

Review

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Review

Software Platforms for Vibroacoustic Simulation of Geared Drivetrains: A Critical Review of Methods, Fidelity Levels, and Current Gaps

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Abstract

The vibroacoustic simulation of geared drivetrains has become increasingly important as electrified powertrains expose tonal gear noise and high-frequency structure-borne excitation more clearly than conventional internal-combustion vehicles. In this context, software choice is no longer a secondary implementation detail but a central engineering decision, because different platforms emphasize different parts of the excitation–transfer–radiation chain. This review therefore examines gearbox and geared-drivetrain NVH simulation from a software-specific perspective rather than a purely phenomenon-based one. The article critically compares dedicated gearbox CAE tools, general multibody dynamics platforms, integrated multiphysics and structural–acoustic finite-element environments, and early-stage 1D system simulation tools. The comparison covers major software ecosystems including KISSsoft/KISSsys, Romax Suite, SMT MASTA/DRIVA, MSC Adams, AVL EXCITE, RecurDyn/DriveTrain, Siemens Simcenter 3D Motion / Transmission Builder / Acoustics, SIMULIA Simpack, Ansys Motion with Mechanical/Acoustics and Motor-CAD, COMSOL Multiphysics, GT-SUITE, and Simcenter Amesim, while also considering relevant recent module extensions and workflow updates. The review shows that the current software landscape is structured around four main methodological layers: dedicated gearbox analysis tools that are strongest in gear-contact modeling and microgeometry iteration; high-fidelity multibody platforms that are strongest in system-level dynamic response and transmission-path representation; integrated structural–acoustic environments that provide the deepest access to housing vibration and radiated-noise prediction; and 1D or multidomain system tools that are most efficient for early concept evaluation and architecture-level trade-off studies. Recent developments since 2023 indicate a clear shift toward tighter support for electrified drivetrain NVH, measured manufacturing deviations, optimization workflows, and faster acoustic prediction, including reduced-order or embedded acoustic methods. At the same time, major gaps remain. Open literature still contains relatively few independent studies that validate the full chain from tooth contact and transmission error through dynamic transfer paths to housing vibration and radiated sound within a single commercial workflow. Likewise, interoperability for measured flank topography, wear-driven NVH evolution, and fully validated electro-magnetic–mechanical–acoustic simulation remains limited and uneven across platforms. For this reason, the review argues that current software ecosystems are best understood not as universally proven end-to-end solutions, but as partially overlapping toolchains with different strengths, evidence levels, and practical compromises.

Keywords: gearbox NVH; gear whine; geared drivetrains; transmission error; loaded tooth contact analysis; mesh stiffness; multibody dynamics; structural acoustics; radiated noise; e-drive NVH; microgeometry optimization; digital twin

1. Introduction

The rapid transition toward electrified mobility has significantly changed the NVH priorities of transmission systems. In conventional vehicles, combustion-related excitation often masks a portion of drivetrain tonal content. In electric powertrains, by contrast, the lower masking effect of the prime mover makes gear-mesh-related tonal components, housing resonances, bearing-transmitted forces, and high-frequency structure-borne phenomena much more perceptible. As a result, the vibroacoustic behavior of geared drivetrains has become a primary design concern rather than a secondary refinement task. Recent reviews on vehicle NVH and electrified drivetrains consistently show that tonal gear noise, structural transfer paths, and the interaction between mechanical and electro-magnetic sources are now central topics in modern powertrain development [1,2].

Within this broader field, transmission error remains one of the most widely used indicators of gear excitation. It is still fundamental for understanding the origin of gear whine, and it remains deeply embedded in both analytical and commercial software workflows. However, both the literature and current industrial practice make it clear that low transmission error alone does not guarantee low radiated noise. The final acoustic outcome depends not only on excitation amplitude, but also on mesh stiffness variation, bearing and shaft dynamics, housing flexibility, structural transfer paths, acoustic radiation efficiency, and, increasingly, coupling with electro-magnetic excitation in e-drives. This is why modern gearbox NVH analysis can no longer be reduced to a single indicator or a single solver layer [3–7].

Despite this, much of the academic literature remains organized primarily around physical phenomena rather than around software ecosystems. There are extensive studies on loaded tooth contact analysis, transmission error, mesh stiffness, housing vibration, flexible multibody simulation, and structural–acoustic coupling. There are also valuable papers on validation strategies and on the influence of uncertainties or manufacturing deviations. However, engineers in practice rarely select methods in isolation. They choose and combine software environments. They need to know which platforms are best suited for microgeometry iteration, which are stronger in dynamic transfer-path representation, which can support radiated-noise prediction, which handle measured geometry most effectively, and which are mature enough for electrified drivetrain workflows. In other words, the engineering question is often not simply “which method is best,” but rather “which software ecosystem is best aligned with the required task and fidelity level.” [8–10]

This distinction is especially important because the open literature still contains only a limited number of explicit software-to-software comparisons. One of the clearest recent examples is the benchmarking study by Bejar et al., which compared commercial gear-contact software in terms of static transmission error response and showed that differences in contact modeling assumptions, flexibility representation, and treatment of microgeometry can lead to non-negligible deviations even before the analyst reaches the full NVH stage. That result is highly relevant, because it demonstrates that software choice can influence predictions already at the excitation level. Likewise, recent validation work on elastic multibody models has shown that the representation of stiffness and flexibility can substantially affect correlation quality between simulation and measurement, reinforcing the idea that the solver architecture itself is a meaningful object of review [10,11].

A software-specific review is therefore justified for at least three reasons. First, the commercial landscape has diversified considerably, with some tools specializing in gear contact and design iteration, others in nonlinear system dynamics, others in structural–acoustic prediction, and others in architecture-level multidomain system simulation. Second, several major vendors have introduced relevant updates since 2023, including new acoustic workflows, electrified drivetrain features, optimization modules, and more explicit support for measured deviations and tolerance handling. Third, there remains a visible gap between vendor-documented capability, peer-reviewed demonstrated application, and fully validated end-to-end workflow maturity, especially when the target is radiated sound rather than internal dynamic quantities alone.

Accordingly, this review does not aim to function as a software catalog. Instead, it provides a structured analytical framework for interpreting the current ecosystem of software platforms used in the vibroacoustic simulation of geared drivetrains. The central objective is to clarify where different

tool categories are strongest: in gear-mesh excitation prediction, loaded tooth contact analysis, flexible multibody dynamics, housing vibration, radiated-noise prediction, e-drive NVH, optimization, and manufacturing-aware workflows. At the same time, the review highlights the current limits of the field, including incomplete interoperability for measured flank topography, limited maturity of wear-driven NVH workflows, and the continuing scarcity of independently validated end-to-end simulation chains from tooth contact to radiated sound.

2. Review Scope and Methodology

This review was designed as a **software-specific** assessment of vibroacoustic simulation platforms for geared drivetrains rather than as a conventional phenomenon-centered NVH survey. The starting scope was the user-provided software list, which already covered the major commercial ecosystems used in gearbox and e-drive simulation, including dedicated gearbox CAE tools, multibody dynamics environments, multiphysics platforms, and early-stage system simulators. That initial list was then expanded only where the open literature or official vendor documentation justified the inclusion of an additional module, workflow, or closely connected platform.

The central premise of the review is that engineers do not select isolated equations or isolated solver classes in practice. They select **software ecosystems** that embody particular modeling philosophies, data structures, interoperability assumptions, and validation traditions. For that reason, the article evaluates software platforms along a common analytical framework instead of describing each tool in isolation. The main comparison axes used throughout the review are: ecosystem type; main solver philosophy; gear-contact and excitation fidelity; system-level dynamic fidelity; flexible body support; structural-acoustic capability; radiated-noise capability; handling of manufacturing deviations; support for measured geometry and flank-topography input; optimization capability; interoperability; industrial workflow maturity; validation maturity; and main practical limitations. This framing is consistent with the way current vendor documentation positions tools such as KISSsoft, Romax Spectrum, MASTA, Simcenter 3D, AVL EXCITE M, Ansys Motion, and Simcenter Amesim, each of which emphasizes a different part of the excitation–transfer–radiation chain.

The literature search combined **peer-reviewed publications** with **official software documentation**. Peer-reviewed sources were used to assess physical methods, benchmark results, workflow demonstrations, and validation evidence. Official vendor sources were used only for documented software capabilities, module definitions, release updates, and version-specific workflow claims. This distinction is essential, because a software feature may be clearly documented by a vendor without yet being demonstrated extensively in the peer-reviewed literature. Conversely, an academic paper may show a successful application using a platform but not fully document the generality or robustness of the commercial workflow. Accordingly, the review separates three evidence levels throughout the text: **vendor-documented capability**, **peer-reviewed demonstrated application**, and **inference based on solver architecture**.

The search covered publications and technical sources relevant to: gear contact analysis; loaded tooth contact analysis; transmission error; mesh stiffness; gearbox vibration; structural-acoustic coupling; radiated noise; e-drive NVH; flexible multibody dynamics; manufacturing deviations; and measured geometry integration. The principal document types considered were journal articles, conference papers, dissertations where technically relevant, official product pages, official help/documentation portals, and official release notes. Particular attention was given to **2023 onward** release information, because recent commercial development has been especially active in the areas of e-drive NVH, microgeometry optimization, embedded acoustics, reduced-order methods, and tolerance-aware workflows. Recent updates from KISSsoft, Romax, MASTA, Simcenter 3D, Simcenter Systems Simulation, and Ansys were therefore treated as important evidence for current capability trends, but not as substitutes for independent validation.

The inclusion logic followed four rules. First, a source was included if it described a software platform or module that is directly relevant to gearbox or geared-drivetrain NVH simulation. Second, a source was included if it presented a peer-reviewed application or validation study using one of

the relevant platforms. Third, a source was included if it clarified a solver philosophy or workflow layer that materially affects interpretation, such as the distinction between excitation-focused and response-focused platforms. Fourth, recent official release information was included if it introduced a new capability that may alter the practical position of a software family in the current market, for example embedded acoustic analysis in MASTA 14, motion-based gear design optimization in Simcenter 3D, tolerance integration in Ansys Motion, or recent Romax release enhancements.

Exclusion criteria were equally important. Low-quality reseller pages, unverified promotional summaries, forum-like claims, and generic marketing statements without technical detail were excluded. Sources were also excluded if they discussed gears in general but did not contribute meaningfully to the vibroacoustic chain from excitation to response or radiation. Similarly, broad NVH papers without gearbox relevance were not used to support gearbox-specific software claims. Where direct software-to-software benchmark studies were unavailable, this limitation was stated explicitly rather than being concealed by overconfident synthesis. This was necessary because the open literature still contains far fewer explicit comparative studies than the practical importance of software choice would suggest. The benchmark study by Bejar et al. on commercial gear-contact software and the recent validation work on elastic multibody drivetrain models are therefore particularly influential in this review, because they show directly that solver assumptions and flexibility representation can materially change predicted results.

A further methodological principle was the separation of **capability** from **validation maturity**. A platform may offer a workflow for gear contact, flexible multibody dynamics, and acoustic radiation within one ecosystem, yet the open literature may validate only part of that chain. For this reason, validation maturity is treated as a dedicated comparison dimension in the manuscript. The review distinguishes, where possible, between evidence at the **gear-pair**, **gearbox**, **drivetrain/e-axle**, **housing-vibration**, and **radiated-noise** levels. This distinction is especially important in current commercial environments, because several platforms now advertise end-to-end workflows, while the peer-reviewed evidence often remains stronger for excitation prediction than for fully validated radiated-noise prediction.

The review also adopts a **task-based interpretation** of model fidelity. In this article, “high fidelity” does not simply mean “more finite elements” or “more physics modules.” It refers to how well a workflow matches the engineering question being asked. A dedicated gearbox CAE environment may be the highest-fidelity choice for rapid microgeometry iteration and excitation ranking, even if it is not the deepest structural-acoustic tool. By contrast, a multiphysics FE environment may be the highest-fidelity choice for housing-radiation studies while being less efficient for large design-space exploration. Similarly, 1D or multidomain system tools may be the most appropriate choice in concept phases even though they are not intended to reproduce full tooth-contact detail. This task-based notion of fidelity is essential for avoiding simplistic rankings of platforms.

Finally, the review is intentionally written as an **analytical synthesis**, not as a catalog. The goal is not to reproduce vendor brochures, but to interpret where current software ecosystems are strongest, where they overlap, and where the open evidence remains thin. In particular, the review pays special attention to four unresolved areas that repeatedly emerged during the search: limited independent end-to-end validation from tooth contact to radiated sound; incomplete interoperability for measured flank topography and manufacturing deviations; immature wear-driven NVH workflows; and uneven maturity in fully integrated electro-magnetic–mechanical–acoustic simulation for electrified drivetrains. These themes define the comparative sections that follow.

3. Taxonomy of Software Platforms for Gearbox Vibroacoustic Simulation

A meaningful review of gearbox vibroacoustic software must begin with taxonomy rather than brand-by-brand description. The current landscape is not a flat list of competing packages that solve the same problem in the same way. Instead, it is composed of several partially overlapping software families that differ in solver philosophy, model hierarchy, workflow maturity, and the part of the excitation–transfer–radiation chain they treat most effectively. Across the platforms examined in this

review, four broad categories can be identified: dedicated gearbox CAE tools, general multibody dynamics platforms with drivetrain-oriented modules, integrated multiphysics and structural-acoustic environments, and early-stage 1D or multidomain system simulation tools. Although some modern ecosystems span more than one category, this four-part classification remains useful because it reflects the dominant engineering role of each platform in practice.

3.1. Dedicated Gearbox CAE Tools

The first category comprises software environments whose primary architecture is built around gears, bearings, shafts, and transmission elements rather than around generic multibody or finite-element abstractions. In the present scope, the clearest representatives are **KISSsoft/KISSsys**, **Romax Suite**, and **SMT MASTA/DRIVA**, although their internal breadth differs significantly. These tools are typically strongest in design-oriented gearbox workflows, transmission error prediction, mesh stiffness evaluation, microgeometry studies, load distribution analysis, and fast engineering iteration at gear-pair, gearbox, or transmission subsystem level. Their major advantage is that the user does not need to assemble a gearbox analysis environment from first principles; the data model, solver flow, and reporting structure are already tailored to gear engineering problems.

Within this group, however, important distinctions remain. **KISSsoft** is fundamentally rooted in gear calculation, geometry, standards-based design, and contact-oriented transmission analysis, while **KISSsys** extends that logic toward system-level transmission modeling and workflow automation. This makes the KISSsoft ecosystem especially strong for excitation-side analysis, design-space iteration, and manufacturing-aware gear evaluation, but less self-sufficient for full structural-acoustic radiation studies without external coupling. **Romax**, by contrast, is organized as a broader drivetrain and e-powertrain ecosystem, with modules that explicitly address durability, efficiency, concept architecture, and NVH; the Spectrum branch is particularly relevant because it positions NVH analysis more centrally inside the gearbox-powertrain workflow. **MASTA** occupies an intermediate position: it remains strongly gearbox-oriented, but its DRIVA extension and recent acoustic developments move it closer to dynamic system analysis than traditional design-calculation packages.

From the standpoint of this review, dedicated gearbox CAE tools can therefore be described as **excitation-centered but increasingly system-aware** platforms. They are usually the most efficient choice when the engineering question is dominated by tooth contact, transmission error, mesh stiffness, load sharing, or microgeometry optimization. They are less universally dominant when the target shifts toward full vehicle-level transfer paths, high-fidelity housing radiation, or multiphysics coupling that extends far beyond the gearbox itself.

3.2. General Multibody Dynamics Platforms with Drivetrain-Oriented Modules

The second major category includes general MBD environments that can model geared systems with high dynamic fidelity, often using dedicated drivetrain or machinery modules. In the present scope, the principal examples are MSC Adams with gear- and vibration-oriented toolkits, AVL EXCITE, RecurDyn/DriveTrain, Siemens Simcenter 3D Motion / Transmission Builder, SIMULIA Simpack, and SIMDRIVE 3D. These platforms are not primarily organized as gear-design calculators. Instead, they are organized around rigid or flexible bodies, joints, contacts, modal reduction, and time-domain or hybrid dynamic simulation, with drivetrain-specific layers added on top.

Their typical strength lies in system-level dynamic response rather than in the earliest stages of gear geometry iteration. In practical terms, they are often preferred when the analyst needs to represent shafts, bearings, splines, housings, mount paths, flexible components, and nonlinear dynamic interactions within a common dynamic model. This makes them highly relevant for transmission-path analysis, dynamic amplification, mode interaction, and subsystem or full-drivetrain NVH assessment. Because these platforms are generally built on mature multibody formalisms, they also tend to provide stronger infrastructure for flexible body coupling than pure gearbox design packages.

Even within this category, the internal balance differs. AVL EXCITE M is strongly associated with powertrain NVH and nonlinear time-domain drivetrain analysis. Simcenter 3D Motion benefits from its deeper integration with the surrounding Siemens structural and acoustic environment, which is particularly important when moving from transmission kinematics toward coupled structural response and acoustics. Simpack is widely positioned as a high-end multibody environment with dedicated NVH-oriented capabilities and extensive flexible-body handling. RecurDyn/DriveTrain gains special relevance through its bridge-like role between general MBD and gear-specific engineering workflows, particularly where KISSsoft-linked definitions are involved. Adams remains important because of its historical role in machinery and powertrain dynamics and because its ecosystem can be extended toward structural and acoustic analysis through connected tools.

For this reason, general MBD platforms are best described as response- and transfer-path-oriented tools with varying levels of embedded gear intelligence. They are usually more appropriate than dedicated gearbox CAE software when the dominant uncertainty lies in dynamic coupling and structural interaction. Conversely, they may be less efficient than dedicated gearbox tools for very rapid gear-microgeometry iteration unless supported by strong specialized modules or external gear-design coupling.

3.3. Integrated Multiphysics and Structural–Acoustic Environments

A third category consists of multiphysics FE-centered environments, represented here mainly by Ansys Motion together with Mechanical/Acoustics and Motor-CAD, and COMSOL Multiphysics with structural, acoustics, and multibody modules. These platforms are not gearbox tools in the narrow sense. Their importance lies instead in the fact that gearbox vibroacoustics often becomes inseparable from structural dynamics, acoustic radiation, thermal effects, and, in electrified systems, electro-magnetic excitation. When the engineering target shifts from “What is the predicted transmission error?” to “How does this excite the housing and radiate sound into the surrounding field?”, FE-centered environments become much more prominent.

The central advantage of this group is physical breadth. These tools can represent structural flexibility, acoustic domains, vibroacoustic coupling, and multiphysics boundary conditions with a depth that is often beyond the normal scope of gearbox-native CAE packages. They are therefore especially relevant for housing vibration studies, radiated-noise prediction, acoustic cavity interaction, and research-oriented workflows in which gearbox excitation is only one part of a larger coupled problem. Official workflows in Ansys and COMSOL explicitly position these environments for structural-acoustic and multiphysics analysis, while the literature on vibroacoustic simulation repeatedly shows that accurate radiation prediction depends heavily on structural and acoustic modeling choices beyond the initial tooth-contact stage.

Their main limitation is not lack of physics, but workflow burden. These environments generally require more model-building effort, more analyst judgment, and more careful coupling strategy than a dedicated gearbox package. As a result, they are rarely the fastest route for early architecture screening or rapid microgeometry iteration. Instead, they are most valuable where the analyst needs deeper physical interpretability or stronger access to structural-acoustic phenomena than dedicated gearbox software typically provides. In taxonomy terms, they are best seen as radiation-capable, high-fidelity environments whose greatest strength appears in the later and more coupled parts of the NVH chain.

3.4. Early-Stage 1D and Multidomain System Simulation Tools

The fourth category includes **system simulation platforms** such as **GT-SUITE** and **Simcenter Amesim**, which are not primarily designed for detailed tooth-contact or structural-acoustic FE analysis, but are highly relevant at concept stage and at architecture level. These tools are particularly important in electrified drivetrains because they allow rapid subsystem integration, control interaction, and system-level trade-off studies before a high-fidelity 3D model is fully available. Their relevance in this review therefore comes from model hierarchy rather than from local contact fidelity.

Their main value lies in **speed, architecture-level integration, and multidomain coupling**. For example, these platforms can be effective for early driveline vibration studies, concept comparison, and system-level parameter sensitivity analysis, especially where electrical, thermal, control, and mechanical domains interact. However, they generally do not aim to replace dedicated loaded tooth contact analysis or high-fidelity structural-acoustic radiation modeling. In this sense, they are best classified as **screening and architecture tools** rather than end-point radiated-noise solvers.

This distinction matters because early-stage system tools are sometimes undervalued in gearbox NVH discussions. Yet in practice, the earliest architectural decisions often determine whether later high-fidelity NVH work will converge efficiently or not. A software taxonomy that ignores these platforms would therefore miss an important layer of real industrial workflow logic, especially in e-drive development programs where packaging, speed range, torque delivery, and electro-mechanical integration must be assessed together from the beginning.

3.5. Cross-Category Overlap and Hybrid Ecosystems

Although the four-category taxonomy is useful, current software ecosystems increasingly blur category boundaries. **MASTA** now extends further into dynamic and acoustic territory than older gearbox-design classifications would suggest. **Simcenter 3D** spans motion, structural simulation, acoustics, and optimization in a more integrated way than a simple MBD label implies. **Ansys** combines multibody, structural, acoustic, and electromagnetic capabilities across linked products. **Romax** also occupies a hybrid position because its suite structure extends from drivetrain architecture and durability to NVH-focused workflows.

For this reason, the taxonomy used in this article should not be interpreted as rigid software pigeonholing. It is instead a **dominant-role classification**. Each platform is assigned to the category that best reflects its most mature and characteristic contribution to gearbox vibroacoustic simulation, while later sections will explicitly discuss overlaps, hybridization, and recent convergence trends. This is particularly important for current vendor development, because several ecosystems are moving toward more continuous end-to-end workflows from gear excitation to acoustic response, even if the validation maturity of those workflows remains uneven.

3.6. Taxonomic Implications for the Rest of the Review

This taxonomy has direct implications for how the remaining sections are structured. The next section will therefore examine not merely “which software exists,” but **which methods are embedded in each software family**, including quasi-static contact formulations, loaded tooth contact analysis, transmission error workflows, flexible multibody dynamics, reduced-order structural models, and structural-acoustic coupling strategies. The comparative sections that follow will then map those method families to engineering tasks such as microgeometry optimization, housing-radiation prediction, e-drive NVH assessment, manufacturing-deviation handling, and wear-informed simulation. In that sense, the taxonomy is not a preliminary cataloging step; it is the organizing logic of the entire review.

Table 1. Taxonomy of software platforms for vibroacoustic simulation of geared systems.

Software ecosystem	Primary category	Typical model level	Dominant strength	Typical best-use scenario	Evidence basis
KISSsoft / KISSsys	Dedicated gearbox CAE	Gear pair to gearbox / transmission system	Gear design, LTCA-oriented contact evaluation, TE-focused microgeometry iteration	Source-side excitation studies, microgeometry optimization, tolerance-sensitive gear refinement	Vendor documentation + peer-reviewed use

Romax Suite / Spectrum / DT	Dedicated gearbox / e-powertrain CAE	Gearbox to drivetrain / e-powertrain	Integrated drivetrain workflow with strong NVH orientation	System-aware gearbox NVH, e-powertrain studies, design-to-NVH workflow continuity	Vendor documentation + limited/open peer-reviewed workflow evidence
SMT MASTA / DRIVA	Dedicated gearbox CAE with dynamic extension	Gear pair to drivetrain subsystem	Transmission analysis plus dynamic extension, growing acoustic accessibility	Gearbox NVH studies needing faster engineering workflow with dynamic extension	Vendor documentation + limited/open peer-reviewed evidence
MSC Adams (+ gear / vibration toolkits)	General multibody dynamics platform	Subsystem to full drivetrain	System dynamics, motion, flexible-body-oriented dynamic workflows	Transfer-path studies, drivetrain dynamics, coupled mechanical subsystem response	Vendor documentation + peer-reviewed method use in MBD literature
AVL EXCITE M	General MBD / powertrain NVH platform	Gearbox to full powertrain / e-drive	Nonlinear drivetrain dynamics and NVH-oriented response modeling	Powertrain dynamic response, subsystem NVH, electrified drivetrain studies	Vendor documentation + peer-reviewed demonstrated application
RecurDyn / DriveTrain	General MBD platform with drivetrain modules	Gearbox to subsystem / drivetrain	Flexible dynamic simulation with bridge-like role to gear-oriented workflows	System response studies when gear-side definitions must connect to general MBD	Vendor documentation + limited/open peer-reviewed evidence
Simcenter 3D Motion / Transmission Builder / Acoustics	Integrated motion-structural-acoustic CAE platform	Subsystem to full system	Cross-domain continuity between motion, structures, and acoustics	Coupled motion-to-structure-to-acoustics workflows, optimization-informed NVH studies	Vendor documentation + peer-reviewed relevance + release evidence
SIMULIA Simpack	General high-fidelity MBD platform	Subsystem to full drivetrain	Flexible-body dynamics and NVH-capable system response	Resonance-sensitive drivetrain dynamics, subsystem	Vendor documentation + peer-reviewed

				NVH, flexible multibody studies	MBD relevance
SIMDRIVE 3D	Full MBS / electromechanical NVH platform	Subsystem to drivetrain / electromechanical system	Integrated multibody and electromechanical workflow orientation	Electromechanical drivetrain studies, digital-master-style workflow environments	Mainly vendor documentation; limited open peer-reviewed evidence identified
Ansys Motion + Mechanical / Acoustics + Motor-CAD	Integrated multiphysics / structural-acoustic environment	Component to full coupled system	Structural-acoustic depth, multiphysics coupling, electro-mechanical extension	Housing vibration, radiated noise, e-drive multiphysics studies	Vendor documentation + peer-reviewed structural-acoustic relevance
COMSOL Multiphysics	Integrated multiphysics / structural-acoustic environment	Component to full coupled system	Research-grade multiphysics and acoustic modeling	High-fidelity research studies of structural-acoustic response and coupled phenomena	Vendor documentation + peer-reviewed multiphysics relevance
GT-SUITE	Early-stage 1D / multidomain system simulation	System / architecture level	Fast multidomain system integration	Early architecture screening, concept-level driveline and e-drive studies	Vendor documentation + limited open peer-reviewed gearbox-NVH-specific evidence
Simcenter Amesim	Early-stage 1D / multidomain system simulation	System / architecture level	Rapid concept-level driveline and system simulation	Early concept comparison, multidomain system-level NVH feasibility assessment	Vendor documentation + limited open peer-reviewed gearbox-NVH-specific evidence

4. Simulation Methods Embedded in the Software Ecosystem

The taxonomy introduced above becomes technically meaningful only when it is connected to the underlying simulation methods. Commercial gearbox NVH software differs not merely by interface design or workflow integration, but by the physical abstractions and numerical strategies embedded in each platform. These embedded methods determine what a tool can represent efficiently, what it can predict robustly, and where it is likely to require coupling with external environments. In practice, the main methodological layers relevant to geared-drivetrain

vibroacoustics are: quasi-static and loaded tooth contact analysis; transmission error and mesh-stiffness evaluation; rigid and flexible multibody dynamics; structural dynamic reduction and component-mode representation; structural–acoustic simulation; and, increasingly, optimization and uncertainty-aware workflows. Although many modern software ecosystems combine several of these layers, they rarely do so with equal maturity across the full excitation–transfer–radiation chain.

4.1. Quasi-Static Contact Analysis, LTCA, and Excitation-Oriented Solvers

At the foundation of most gearbox NVH workflows lies some form of **gear-contact analysis**, whether expressed explicitly as loaded tooth contact analysis (LTCA), flank load distribution, local compliance analysis, or a closely related quasi-static mesh formulation. The purpose of this layer is to determine how geometry, load, misalignment, and microgeometry modifications shape contact conditions across the mesh cycle. In dedicated gearbox CAE environments, this contact-oriented level is usually the most mature part of the software. It is here that the analyst evaluates tooth contact position, load sharing, local compliance effects, static transmission error, mesh stiffness variation, and the influence of tip relief, lead crowning, profile correction, or flank deviations. This is also the methodological level at which commercial software differences can begin to emerge measurably, as shown by comparative work on static transmission error prediction in commercial gear-contact software.

The key strength of these quasi-static solvers is efficiency. They are generally much faster than full nonlinear structural dynamic or full-contact finite-element models, yet they preserve the contact quantities most directly associated with tonal gear excitation. This makes them highly suitable for design iteration, parameter screening, tolerance studies, and microgeometry optimization. KISSsoft, Romax, and MASTA all position this layer as a core capability, though with different surrounding ecosystem logic. In KISSsoft, contact and gear calculation remain central. In Romax, the contact layer is integrated into broader drivetrain workflows. In MASTA, it supports both classical transmission analysis and dynamic extensions.

At the same time, quasi-static contact analysis has a clear boundary: it predicts **excitation**, not the entire acoustic outcome. Even when static transmission error and mesh stiffness are estimated with high quality, the final radiated sound depends on downstream system dynamics and radiation efficiency. For this reason, excitation-oriented solvers should be interpreted as necessary but not sufficient for full vibroacoustic prediction. This distinction is consistently supported by the broader NVH literature, which shows that radiation problems depend strongly on structural modes, damping, transfer paths, and acoustic boundary conditions in addition to mesh excitation itself.

4.2. Transmission Error and Time-Varying Mesh Stiffness as Embedded Interface Quantities

Among all internal variables used in commercial gearbox NVH workflows, **transmission error (TE)** and **time-varying mesh stiffness (TVMS)** remain the most widely shared interface quantities between contact analysis and dynamic response simulation. They are not always computed in identical form across platforms, but they function similarly: they translate tooth-level interaction into system-level excitation. TE is often treated as a displacement-type excitation descriptor, whereas mesh stiffness and related contact-force representations provide the stiffness or forcing pathway by which tooth interaction enters the drivetrain model. In practice, many commercial workflows either export these quantities directly into multibody or structural solvers or embed them inside a coupled solver chain.

This methodological role makes TE and TVMS particularly important in software comparison. Tools that are strong in TE and mesh-stiffness estimation are often strong in **gear whine source prediction**, even if they are not the strongest in later response or radiation stages. Conversely, platforms that emphasize dynamic transfer-path analysis may rely on upstream TE- or stiffness-type inputs supplied by another layer or another tool. This division of labor explains why excitation-focused packages and response-focused packages often coexist in industrial workflows rather than replacing one another.

A related methodological issue is that TE is not a single universally comparable quantity across all studies and software implementations. Static TE, quasi-static TE under load, and dynamic TE are not equivalent. Some workflows emphasize low-order harmonic content, whereas others use TE as a time-history input for downstream simulations. For a software review, this means that “TE capability” must not be treated as a simple yes/no label. What matters is how the software defines TE, how it links TE to flexibility and misalignment, and whether the resulting quantity is intended for ranking excitation risk, driving a reduced-order dynamic model, or supporting a more complete NVH chain.

4.3. Rigid and Flexible Multibody Dynamics

Once excitation has been defined, the next major methodological layer is **multibody dynamics (MBD)**. This layer becomes dominant when the engineering question concerns dynamic transfer, mode interaction, amplification, transient behavior, or subsystem-to-system coupling. In gearbox NVH, MBD is especially important because the same mesh excitation can produce very different dynamic responses depending on bearing arrangement, shaft flexibility, spline compliance, housing coupling, mount conditions, and operating speed. General MBD platforms such as AVL EXCITE M, Simpack, Simcenter 3D Motion, Adams, and RecurDyn are designed precisely for this class of problem, and some dedicated gearbox ecosystems increasingly incorporate similar logic.

A crucial distinction within MBD is the difference between **rigid-body** and **flexible-body** representation. Rigid-body MBD can be sufficient for some architecture-level or low-frequency dynamic questions, but it becomes progressively less adequate when shaft bending, housing flexibility, local compliance, mode localization, or higher-frequency NVH mechanisms become important. Flexible MBD introduces reduced structural descriptions—typically modal or component-mode-based—that allow local elasticity to affect global dynamics without requiring full finite-element solution at every time step. The literature on elastic multibody validation confirms that the inclusion and treatment of flexibility can materially influence agreement between simulation and experiment, which is why flexible-body support is treated as a central comparison dimension in this review.

In methodological terms, MBD platforms can be viewed as the core tools for **dynamic transfer-path representation**. They are particularly strong when the analyst needs to move beyond local mesh behavior and ask how excitation propagates through shafts, bearings, couplings, housings, and support structures. Their weakness is not insufficient dynamics, but rather that detailed tooth-contact fidelity may not be native or may require dedicated submodules, imported data, or upstream coupling. This is why software ecosystems that bridge dedicated gearbox contact models with flexible MBD remain especially relevant in practice.

4.4. Time-Domain, Frequency-Domain, and Hybrid Workflows

One of the most important but often under-discussed methodological distinctions in commercial software is the choice between **time-domain**, **frequency-domain**, and **hybrid** workflows. Time-domain simulation is especially valuable when nonlinearities, transient events, load changes, or strongly time-varying interactions dominate the problem. Frequency-domain approaches, by contrast, are often more computationally efficient for steady-state tonal phenomena and can provide clearer access to harmonic transfer mechanisms. Hybrid workflows attempt to combine the two, for example by using quasi-static contact calculations to extract excitation terms and then applying frequency-response or modal superposition approaches downstream.

This distinction matters greatly in gearbox vibroacoustics. Classical gear whine under steady operating conditions is often well suited to harmonic or frequency-domain treatment, especially when the objective is to assess tonal peaks near gear-mesh harmonics and housing resonances. On the other hand, startup events, load transitions, backlash-related behavior, or certain nonlinear contact phenomena may require time-domain treatment to avoid oversimplification. Commercial platforms differ significantly in how naturally they support these alternatives. AVL EXCITE and Simpack are particularly explicit about combined nonlinear dynamic and NVH workflows. MASTA

also bridges quasi-static and dynamic logic. Simcenter 3D and Ansys-based chains can support both harmonic and transient structural-acoustic treatments depending on the coupled workflow.

For this reason, the best software choice is often determined not by absolute accuracy in the abstract, but by the **dominant temporal structure of the engineering question**. A time-domain-capable environment is not automatically preferable if the design task is dominated by rapid steady-state comparison across many variants. Likewise, a frequency-domain-centric workflow may be insufficient when strongly nonlinear transients are central. The increasing use of hybrid workflows across vendors is therefore a rational response to the fact that gearbox NVH problems rarely remain purely local or purely linear across the entire development process.

4.5. Reduced-Order Structural Modeling and Component-Mode Representation

Between multibody dynamics and full structural FE simulation lies an important methodological intermediate layer: **reduced-order structural modeling**. This typically involves modal reduction, flexible-body condensation, or component-mode synthesis approaches that preserve the dominant structural dynamics of shafts, housings, carriers, and other components while keeping computation manageable. In gearbox NVH practice, this layer is essential because a fully detailed structural model is often too expensive for routine design iteration, while a purely rigid representation may omit exactly the resonant features that control dynamic amplification and acoustic radiation.

Many advanced commercial environments rely on this methodological compromise. Flexible multibody formulations in Simpack, Simcenter 3D, AVL EXCITE, Adams-connected workflows, and RecurDyn-linked environments all make use of some reduced structural representation. The practical meaning of this is that gearbox vibroacoustic simulation often depends less on whether a tool uses “FE” in a general sense and more on **how it reduces FE information into a usable dynamic form**. A platform that supports robust flexible-body integration with sensible modal truncation can often answer system-level NVH questions more effectively than a nominally richer model that is too computationally heavy for iterative use.

This methodological layer also explains why the boundaries between MBD tools and structural tools have become less distinct in recent years. Once reduced-order structural behavior is embedded in the system model, the software no longer acts as a purely kinematic drivetrain simulator. It becomes a dynamic response environment capable of addressing modal amplification, path sensitivity, and housing-coupled excitation with much greater realism than rigid-only models.

4.6. Structural–Acoustic Simulation and Radiated-Noise Prediction

The next layer in the chain is structural–acoustic simulation, which becomes central when the target variable is no longer internal dynamic force or vibration level, but radiated noise. This methodological transition is critical because a gearbox can have measurable dynamic excitation without necessarily radiating efficiently at the same frequencies. Acoustic prediction therefore requires not only excitation and structural response, but also an appropriate representation of radiation efficiency, acoustic boundary conditions, fluid loading, enclosure effects, and, in some cases, cavity coupling. The literature on radiated gearbox noise makes clear that these effects cannot be inferred reliably from excitation indicators alone [12,13].

Commercial software differs sharply at this stage. FE- and acoustics-centered environments such as Ansys and COMSOL are naturally strong here because they are built to solve structural and acoustic field problems directly. Simcenter 3D also benefits from explicit structural and acoustic integration inside a broader CAE framework. Romax Spectrum and recent MASTA developments show a parallel commercial trend toward **embedded or accelerated acoustic prediction** within gearbox-native ecosystems, which is highly attractive for industrial iteration speed. However, the existence of an embedded acoustic workflow should not be interpreted automatically as equivalent to the deepest possible structural–acoustic treatment. The methodological trade-off is usually between speed and completeness rather than between capability and incapability in a binary sense.

This is one of the clearest areas where the distinction between **vendor-documented capability** and **peer-reviewed validation maturity** becomes essential. A software ecosystem may document housing-response and radiated-noise workflows convincingly, yet the peer-reviewed open literature may still offer only limited independent evidence for specific use cases or operating regimes. For a critical review, this means that radiated-noise capability must always be interpreted together with the strength of the published validation basis.

4.7. Optimization, Tolerance Handling, and Manufacturing-Aware Workflows

A major recent trend in gearbox software is the growing integration of optimization and manufacturing-aware simulation. Historically, gear microgeometry optimization was already a central topic in dedicated gearbox tools, because small geometric changes can alter contact distribution and TE significantly. More recently, however, software development has moved beyond nominal optimization toward tolerance-aware and measured-geometry-aware workflows. This includes support for design exploration, sensitivity studies, and, in some ecosystems, closer linkage between geometry variation and downstream NVH assessment. KISSsoft, Romax, Simcenter 3D, and Ansys workflows all show movement in this direction, though with different emphasis and evidence bases [14].

From a methodological perspective, optimization is not a separate solver class but a meta-layer that acts on top of contact, dynamic, or acoustic models. Its importance in software review lies in how efficiently the software allows repeated analysis under changing geometry, tolerance, or operating conditions. Dedicated gearbox tools often perform well here because their reduced-order contact models are fast enough for repeated evaluation. High-fidelity multiphysics platforms, by contrast, may offer deeper physical insight but at a substantially higher computational price, which makes broad optimization or uncertainty propagation more difficult unless surrogate or reduced-order methods are introduced.

This difference has practical significance for industrial NVH engineering. Many real development questions are not single-run prediction problems, but many-variant comparison problems. In such contexts, software that is slightly less complete physically but dramatically more efficient computationally may provide greater engineering value during earlier design phases. The current market trend toward built-in optimization, tolerance support, and faster acoustic estimation reflects this industrial need rather than a purely academic search for ever more detailed individual models.

4.8. Measured Geometry, Flank Topography, and Wear-Driven Extensions

One of the least mature but increasingly important methodological frontiers concerns the treatment of measured manufacturing deviations, measured flank topography, and wear-driven geometry evolution. From a physical standpoint, these topics are highly relevant because real gearbox NVH depends not only on nominal design geometry, but also on production variation, surface deviations, assembly effects, and life-state changes. From a software standpoint, however, this is precisely where the gap between theoretical desirability and practical maturity becomes most visible. The literature increasingly recognizes the importance of manufacturing-induced variation and evolving tooth geometry, but mainstream commercial workflows still handle these topics unevenly [8,9,15].

Methodologically, these problems are difficult because they require more than just another solver module. They require standardized data import, stable mapping of measured deviations onto analysis-ready geometry, repeated re-evaluation of contact and dynamics, and, in wear problems, iterative geometry update through life states. Some commercial ecosystems provide partial routes toward these goals through microgeometry definition, imported deviations, or tolerance workflows, but the open literature still offers relatively limited evidence for fully robust, end-to-end commercial workflows in this area. This is why the present review treats measured-topography handling and wear-driven NVH not as established mature categories, but as emerging capability zones with uneven documentation and validation maturity.

4.9. Methodological Implications

Taken together, these methodological layers show why no single software family dominates every part of the gearbox vibroacoustic problem. Dedicated gearbox CAE tools remain especially strong in contact, TE, and fast design iteration. General MBD platforms remain strongest in representing dynamic transfer and structural interaction at subsystem and system level. FE-centered multiphysics environments remain strongest in detailed structural–acoustic treatment and radiated-noise studies. Early-stage multidomain tools remain strongest in architecture-level speed and integration. The real engineering challenge is therefore not selecting the “best” method in the abstract, but selecting the **appropriate methodological chain** for the problem being asked, while remaining aware of where software-native capability ends and coupled workflow dependence begins.

Table 2. Main modeling methods and fidelity levels used by each software ecosystem.

Software ecosystem	Main solver philosophy	Contact / excitation fidelity	System-level dynamic fidelity	Structural-acoustic capability	Radiated-noise capability	Validation maturity in open literature
KISSsoft / KISSsys	Gear-centered analytical / semi-analytical and contact-oriented workflow	High for gear-contact / TE-oriented tasks	Moderate	Low to moderate natively	Limited natively	Stronger at gear-pair / excitation layer than at full radiation layer
Romax Suite	Hybrid drivetrain CAE with integrated subsystem logic	High to moderate	High at gearbox / drivetrain level	Moderate, ecosystem-dependent	Moderate, especially via Spectrum-style workflows	Stronger for drivetrain and NVH workflow evidence than for universal end-to-end radiation validation
MASTA / DRIVA	Gearbox analysis plus dynamic extension	High to moderate	Moderate to high	Moderate and increasing	Moderate / embedded-access type	Growing workflow breadth, but open full-chain validation remains limited
Adams	General nonlinear multibody dynamics	Moderate unless enhanced by dedicated	High	Moderate via coupled environments	Moderate via extended workflows	Strong MBD pedigree; gearbox-radiation chain less

		d gearing workflow				uniformly documented
AVL EXCITE M	Nonlinear drivetrain MBD and NVH workflow	Moderate to high depending on setup	High	Moderate	Moderate	Good subsystem / powertrain relevance; full excitation-to-radiation evidence remains less uniform
RecurDyn / DriveTrain	General flexible MBD with drivetrain module logic	Moderate to high with linked gear definitions	High	Low to moderate	Limited to moderate through extended chains	Limited open gearbox-NVH-specific validation visibility
Simcenter 3D	Integrated motion + structural + acoustic CAE	Moderate to high	High	High	High	Strong cross-domain potential; open literature still stronger on layers than on universal full-chain proof
Simpack	High-fidelity flexible multibody dynamics	Moderate to high	High	Moderate	Moderate	Strong flexible-body and dynamic response relevance; full radiated-noise maturity depends on workflow coupling

SIMDRIVE 3D	Integrated electromechanical MBS workflow	Moderate	High	Moderate	Moderate	Mostly vendor-documented in reviewed material; limited open validation visibility identified
Ansys ecosystem	Multiphysics FE + motion + acoustics	Moderate to high	High	High	High	Particularly strong for structural-acoustic depth; gearbox-specific end-to-end evidence still selective
COMSOL	Multiphysics FE-centered workflow	Moderate to high	Moderate to high	High	High	Strong research capability; industrial gearbox-specific workflow maturity more case-dependent
GT-SUITE	1D multidomain system simulation	Low to moderate	Moderate to high at architecture level	Low natively	Limited	Best interpreted as concept/system tool, not detailed contact-to-radiation solver
Simcenter Amesim	1D multidomain system simulation	Low to moderate	Moderate to high at concept level	Low natively	Limited	Best for concept-level system studies rather

						than high-detail gearbox NVH closure
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5. Recent Developments and Emerging Trends in the Software

The recent evolution of gearbox vibroacoustic software has been shaped less by the appearance of entirely new solver classes than by the **progressive convergence of previously separate workflow layers**. Over the last few years, commercial development has moved in four visibly connected directions: stronger support for electrified drivetrain NVH; tighter integration between gear-contact analysis and system-level dynamics; broader incorporation of optimization and tolerance-aware workflows; and faster access to acoustic response prediction within environments that were originally centered on contact or drivetrain mechanics. These developments do not eliminate the traditional distinctions between dedicated gearbox CAE tools, multibody environments, and multiphysics platforms, but they do reduce the practical distance between them.

5.1. Stronger Focus on Electrified Drivetrain NVH

One of the clearest recent trends is the explicit repositioning of commercial software toward **electrified powertrain and e-axle NVH**. This shift is not surprising. In e-drives, tonal gear-mesh excitation is more exposed, high-frequency structure-borne content becomes more prominent, and mechanical excitation increasingly has to be interpreted together with electro-magnetic and inverter-related sources. Official product positioning across several vendors now reflects this reality. Romax presents its suite explicitly within e-powertrain development workflows. Simcenter Systems Simulation and Simcenter 3D have strengthened their messaging around electric machine and driveline NVH. Ansys increasingly emphasizes connected electro-mechanical workflows through Motion, Mechanical, Acoustics, and Motor-CAD. AVL EXCITE likewise continues to position itself strongly in electrified powertrain analysis.

From an analytical standpoint, this is more than a marketing shift. It signals that modern gearbox NVH software is increasingly expected to support **multi-source tonal interpretation**, not just classical isolated gear-contact evaluation. In practical terms, this means that software ecosystems are being judged more often on whether they can participate in e-axle-level workflows, whether they can represent higher-frequency structural effects, and whether they can connect mechanical gear excitation to broader electrified system behavior. The literature on e-drive NVH and radiated drivetrain noise strongly supports the importance of this transition, even if the maturity of fully validated commercial end-to-end workflows still varies substantially.

5.2. Tighter Integration Between Gear-Design Workflows and Dynamic System Simulation

A second major trend is the growing attempt to bridge **gear-design-oriented analysis** and **system-level dynamic response modeling** more seamlessly. Historically, the software landscape was more sharply divided: dedicated gearbox tools were used to predict contact-driven excitation, while separate dynamic platforms handled flexible-body interaction, resonance, and transfer paths. That division still exists, but recent software development shows repeated efforts to narrow it.

This trend is visible in several directions. Romax continues to develop its suite logic so that contact, driveline, and NVH considerations sit inside one broader ecosystem. MASTA's dynamic and acoustic extensions reduce the distance between classical transmission analysis and more explicit vibration and sound-response workflows. Simcenter 3D has strengthened the connection between motion-based transmission modeling and design optimization. RecurDyn remains relevant partly because it operates as a bridge between general multibody dynamics and dedicated gear-definition logic through DriveTrain-related coupling.

Technically, the importance of this trend is that **TE- and contact-oriented source models are increasingly expected to flow directly into subsystem or full-system dynamic environments**. This reduces handoff friction and can improve consistency across geometry, loading, and response interpretation. At the same time, such integration must still be assessed critically. A tighter workflow does not automatically imply that every internal method is equally mature across the chain. The gap between smooth workflow integration and deeply validated predictive fidelity remains one of the central interpretive themes of this review.

5.3. Growth of Optimization and Design-Space Exploration Capabilities

A third major development is the stronger embedding of **optimization, design-space exploration, and geometry refinement workflows**. This is especially visible in recent vendor developments that move beyond static analysis menus toward more explicit optimization-oriented applications. A particularly clear example is the emergence of **Simcenter 3D Motion Gear Design Optimization**, which directly targets macrogeometry and microgeometry design decisions in a motion-driven environment. KISSsoft's recent releases also continue to strengthen workflow support around manufacturing-related analysis and design exploration. Romax and Ansys likewise show broader movement toward tolerance-aware or optimization-connected engineering workflows.

This development matters because gearbox NVH is inherently a **many-variant engineering problem**. In practice, analysts rarely evaluate a single nominal design in isolation. They compare relief variants, lead modifications, bearing settings, shaft configurations, housing concepts, and toleranced deviations across operating points. Software ecosystems that support repeated, automated, or optimization-linked evaluation therefore gain strategic importance, even when they do not contain the single deepest physics model in every subdomain. The recent commercial emphasis on optimization suggests that vendors increasingly recognize this industrial reality.

5.4. Increasing Availability of Embedded or Accelerated Acoustic Workflows

Another notable recent trend is the movement toward **faster access to acoustic response prediction** inside software ecosystems that were not originally built as full structural-acoustic research platforms. This does not mean that the deepest structural-acoustic methods have become unnecessary. Rather, it means that the software market is trying to reduce the cost of reaching acoustically interpretable results earlier in the design process.

Two developments are particularly important here. First, **MASTA 14** introduced an integrated acoustic analysis capability, which is significant because it reduces the separation between transmission-oriented dynamic analysis and sound-related output assessment. Second, Romax Spectrum continues to position itself around NVH prediction with acoustic relevance embedded inside the gearbox-powertrain workflow. These are important signals that dedicated or semi-dedicated gearbox ecosystems are no longer satisfied with stopping at internal dynamic indicators alone.

However, this trend must be interpreted carefully. Embedded acoustic workflows are valuable because they shorten iteration cycles and improve accessibility. Yet they do not automatically replace the need for deeper FE/BEM-style structural-acoustic studies where the research question is explicitly about detailed housing radiation, cavity interaction, or complex acoustic boundary conditions. In other words, the current software trend is toward **acoustic accessibility**, not necessarily full convergence toward a single universal acoustic method.

5.5. More Explicit Treatment of Tolerances and Manufacturing Variation

Recent software development also shows growing recognition that nominal geometry alone is not sufficient for robust NVH engineering. This is reflected in the stronger appearance of **tolerance-aware** and **manufacturing-aware** workflows. Ansys has highlighted tolerance-related and geometry-variation-oriented workflow directions within its simulation ecosystem. KISSsoft has continued to emphasize manufacturing-linked capabilities. More broadly, the commercial emphasis on

optimization and geometry handling increasingly suggests that production variability is being treated as a first-class engineering concern rather than a late-stage exception.

This trend aligns well with the broader technical literature, which increasingly emphasizes the NVH relevance of manufacturing deviations, assembly variation, and surface/topography effects. Yet software maturity here remains uneven. The recent commercial movement is best interpreted as **partial progress** rather than full resolution. Support for nominal tolerance studies is advancing more visibly than truly seamless ingestion and dynamic propagation of measured flank topography across the full contact-to-radiation chain.

5.6. Continued Importance of Hybrid Workflows Rather than Single-Environment Dominance

Although vendors are broadening their ecosystems, the recent market direction does not point to a single platform replacing all others. Instead, it points to the persistence—and even formalization—of **hybrid workflows**. A likely practical pattern remains the combination of a strong excitation-side or gear-design-side tool with a strong system-dynamics environment, and, where necessary, a deeper structural-acoustic environment for final radiation studies. Recent developments reinforce this layered logic rather than removing it. Romax broadens internally but does not eliminate the relevance of structural-acoustic specialists. Simcenter strengthens cross-domain continuity but still spans multiple methodological layers. Ansys and COMSOL remain powerful for coupled physics, but they do not become dedicated gearbox-native design environments simply by being multiphysics-capable.

For practitioners, this means that recent software evolution should be interpreted as the rise of **better-connected toolchains**, not as proof that software selection has become trivial. On the contrary, the increased breadth of commercial offerings makes task-aware selection more important, because engineers must now decide not only which software is strongest in isolation, but also which ecosystem transitions are most reliable and efficient for the specific fidelity chain they need.

5.7. Emerging Attention to Digital Twins, Lifecycle Thinking, and Measured-Data Integration

A further emerging trend is the growing use of the language of **digital twins**, **measured-data connection**, and **lifecycle-aware workflows**. This is especially visible in broader platform ecosystems such as Romax and SIMDRIVE-type environments, where the commercial narrative increasingly links design models to operational or system-level interpretation. At the same time, the open literature and current workflow announcements suggest that the most technically meaningful form of this trend in gearbox NVH is not digital-twin branding by itself, but the slow movement toward workflows that can absorb more realistic geometry, tolerances, and subsystem interaction data.

Here again, caution is needed. The term “digital twin” is used broadly in industry, but the peer-reviewed evidence for fully mature digital-twin-style gearbox NVH workflows remains much more limited than vendor terminology may suggest. For this reason, the current review interprets digital-twin-related software trends as **promising but still unevenly substantiated**, particularly when the target is predictive radiated sound or evolving life-state NVH rather than model-connected monitoring in a looser sense.

5.8. Interpretation of Recent Developments

Taken together, recent developments do not overturn the basic taxonomy presented earlier. Dedicated gearbox CAE tools remain strongest where efficient contact and excitation iteration is needed. Multibody environments remain strongest where dynamic transfer and structural interaction dominate. Multiphysics FE environments remain strongest where detailed structural-acoustic treatment is essential. Early-stage multidomain tools remain strongest where architecture-level speed is the key requirement. What has changed is that the boundaries are becoming more permeable. Vendors increasingly add capabilities that reduce workflow discontinuity, especially in optimization, acoustic accessibility, and electrified drivetrain support.

The analytical consequence is straightforward: **recent software progress is real, but it should be read as convergence without full equivalence**. Commercial ecosystems are becoming broader, but the evidence for equal maturity across all layers of the excitation–transfer–radiation chain remains uneven. This is precisely why the next section must move from capability trends to a more task-based comparison of which software categories are most appropriate for specific engineering use cases.

6. Comparative Assessment by Engineering Use Case

A software review becomes practically useful only when general capability descriptions are translated into **engineering use cases**. In gearbox vibroacoustics, software is rarely chosen because it is globally “better” in an abstract sense. It is chosen because a development team needs to solve a particular problem under specific fidelity, speed, interoperability, and validation constraints. For that reason, this section compares software categories according to the dominant task rather than according to vendor branding. The discussion follows the logic established earlier: some workflows are primarily **excitation-oriented**, some are primarily **response-oriented**, and others are most valuable because they support fast concept-level iteration across a broad system context.

6.1. Gear Mesh Excitation Prediction and Transmission Error-Oriented Studies

When the primary objective is to understand **where tonal excitation originates**, the most suitable software category is usually the **dedicated gearbox CAE environment**. This is the case for studies centered on loaded tooth contact analysis, static or quasi-static transmission error, mesh stiffness variation, load distribution, and the sensitivity of these quantities to microgeometry modifications. In such tasks, the main challenge is not yet the full structural-acoustic response of the system, but the physically credible prediction of the source terms that later drive dynamic behavior. KISSsoft, Romax, and MASTA are particularly well aligned with this use case because their workflows are built around contact-relevant quantities rather than requiring the user to assemble the contact logic indirectly from more generic solver infrastructure.

This is also the use case in which software-specific differences can emerge very early, before any housing or acoustic model is even involved. The comparative study by Bejar et al. is especially relevant here, because it demonstrated that commercial gear-contact programs can yield different static transmission error predictions under nominally similar conditions, reflecting different modeling assumptions and internal implementations. That finding strongly supports the view that software choice is already consequential at the source-modeling stage.

For this reason, dedicated gearbox tools are generally the most appropriate choice for **gear whine source ranking, microgeometry variant screening, tolerance sensitivity at the tooth-contact level, and design-space exploration around mesh excitation**. Their main limitation is that they do not automatically provide equally mature prediction of how that excitation will be transmitted, amplified, and radiated by the full mechanical system.

6.2. Microgeometry Optimization and Manufacturing-Aware Gear Refinement

A closely related but distinct use case is **microgeometry optimization**, especially where the goal is to reduce TE peaks, smooth contact distribution, or balance load under misalignment-sensitive operating conditions. This use case differs from source diagnosis because it is explicitly iterative. The software must not only predict excitation, but do so quickly and repeatedly over many candidate geometries. Here again, dedicated gearbox CAE platforms are usually the strongest first choice. Their relative efficiency and native support for gear engineering parameters make them well suited to repeated relief and correction studies. Recent developments in KISSsoft and Simcenter 3D, and broader optimization-oriented directions in Romax and Ansys, confirm that commercial ecosystems increasingly recognize optimization as a central practical need rather than a secondary add-on.

However, the preferred software choice becomes less straightforward when optimization needs to include **structural response** or **system-level NVH objectives** rather than tooth-contact measures

alone. In such cases, a dedicated gearbox environment may still be the most efficient upstream optimizer, but it may need to be linked to a multibody or structural-acoustic environment for downstream confirmation. This illustrates a recurring pattern across the review: the best software for early optimization is often not the same as the best environment for final confirmation.

6.3. Dynamic Transfer-Path Analysis at Gearbox or Subsystem Level

When the main question is no longer “What is the excitation?” but rather “How does the system respond dynamically to that excitation?”, the preferred software category shifts toward **general multibody dynamics platforms**, particularly those with strong flexible-body support and drivetrain-oriented modules. This is the case for tasks involving shafts, bearings, splines, housing coupling, resonant amplification, mount-path sensitivity, and subsystem dynamic interaction. AVL EXCITE M, Simpack, Simcenter 3D Motion, Adams, and RecurDyn are especially relevant in this regime because they are designed to handle interacting mechanical subsystems rather than only local contact quantities.

This category is particularly appropriate for **gearbox-level or driveline-level vibration studies, modal interaction assessment, bearing-force transmission analysis, and flexible-body transfer-path problems**. It is also where the distinction between rigid and flexible representation becomes decisive. The validation literature on elastic multibody drivetrain models makes clear that flexibility representation can strongly affect predictive quality, so platforms with robust flexible-body handling gain a major advantage in such use cases.

The main compromise is that contact fidelity may not be equally native across all MBD platforms. Where high-confidence tooth-contact prediction is essential, the analyst often benefits from coupling an excitation-side gearbox tool to a response-side multibody tool rather than expecting a single model layer to dominate both tasks equally.

6.4. Housing Vibration and Structural Response Studies

A further shift occurs when the engineering target becomes **housing vibration, local structural response, or panel-mode sensitivity**. At this point, the question is no longer purely a drivetrain-dynamics question, because the gearbox housing itself becomes a central filtering and amplifying element. This use case often sits between multibody and structural-acoustic analysis. It can sometimes be handled with flexible multibody tools if the structural model is reduced appropriately, but it increasingly favors environments with stronger structural simulation infrastructure, especially when local mode shapes, panel participation, and vibration field interpretation are important. Simcenter 3D, Ansys-based workflows, and COMSOL gain particular relevance here, while Romax, EXCITE, or Simpack may contribute upstream dynamic loading and system context.

This use case is important because many practical gearbox NVH problems are not dominated by the absolute size of the excitation alone, but by **how the housing responds to it**. A modest change in stiffness distribution, ribbing, boundary condition, or modal density can alter the radiated outcome significantly even if the source excitation changes little. Accordingly, software choice for housing studies should prioritize structural interpretability and coupling quality rather than contact speed alone.

6.5. Radiated-Noise Prediction

When the target variable is explicitly **radiated sound**, the most suitable software category is usually the **integrated structural-acoustic or multiphysics environment**, or a workflow with explicit acoustic capability that is well connected to it. At this stage, the solver must represent not only excitation and structural response, but also acoustic radiation behavior. Ansys and COMSOL are naturally strong here because they are built for structural-acoustic field simulation. Simcenter 3D is also well positioned because it integrates motion, structural response, and acoustics within a common CAE environment. Romax Spectrum and recent MASTA developments point to a parallel industrial

desire for more accessible radiated-noise prediction inside gearbox-native workflows, which is valuable for faster iteration.

The correct critical interpretation, however, is that **radiated-noise capability is not a single yes/no attribute**. Some software ecosystems provide deep direct access to structural-acoustic modeling, while others provide embedded or reduced-order acoustic estimation. Both can be useful, but not for the same purpose. The former is usually preferable when detailed acoustic fidelity is the research target. The latter is often preferable when design iteration speed matters and approximate acoustic interpretability is sufficient in earlier project phases.

This use case also exposes one of the field's most important evidence gaps: open, independent validation of the full chain from gear contact through structural response to radiated sound remains much rarer than validation of excitation metrics alone. For that reason, software selection for radiated-noise work should be made with particular caution regarding validation maturity.

6.6. Electrified Drivetrain and E-Axle NVH Studies

A particularly important current use case is **electrified drivetrain NVH**, especially in e-axes where tonal gear whine, high-frequency structure-borne content, and multi-source interaction become especially prominent. This use case differs from traditional gearbox NVH because the problem is no longer purely mechanical. The analyst may need to consider how gear excitation interacts with electro-magnetic or inverter-related excitation and how this combined forcing propagates through a compact, tightly integrated e-drive structure. Software ecosystems that are well suited to this use case are therefore not necessarily those that are strongest only in tooth contact, but those that can participate in broader cross-domain workflows. Romax, Simcenter, Ansys, and AVL EXCITE are especially relevant here because their ecosystems explicitly address electrified powertrain development. Early-stage multidomain tools such as Amesim and GT-SUITE also become more important in e-drive work than they might appear in a classical gearbox-only context, because architecture-level trade-offs and cross-domain interactions matter early.

For this use case, the best software choice often depends on which aspect dominates. If the core uncertainty lies in mesh excitation, a dedicated gearbox tool may still be the right upstream environment. If the challenge lies in subsystem coupling or tonal propagation through the e-axle structure, an MBD or integrated CAE environment becomes more suitable. If architectural integration and cross-domain feasibility are the main questions, 1D or multidomain system tools gain value. This is precisely why electrified drivetrain NVH tends to reinforce layered toolchains rather than a single-software solution.

6.7. Measured Manufacturing Deviations and Flank Topography Handling

When the engineering problem involves **real measured deviations**, such as CMM-derived flank topography, production-induced variation, or deviation-aware correlation studies, software suitability becomes more uneven. This is not because the issue is physically marginal, but because it requires robust interoperability and geometry-to-solver mapping rather than just one more analysis module. Dedicated gearbox ecosystems with stronger microgeometry logic often provide the most natural starting point for nominal deviation handling, but the maturity of full measured-topography ingestion and its propagation through downstream NVH workflows remains inconsistent across the commercial landscape.

For this use case, no single software category can yet be considered universally mature. Dedicated gearbox tools are often the most natural point of entry because they are already organized around flank geometry and contact effects. However, once measured deviations must influence system response and possibly radiated sound, the workflow usually becomes hybrid and evidence becomes thinner. This makes manufacturing-aware NVH one of the clearest examples where **vendor-documented capability, peer-reviewed application, and fully demonstrated end-to-end maturity** must be kept clearly separate.

6.8. Wear-Driven NVH Studies and Lifecycle-Oriented Simulation

A similarly challenging use case is **wear-driven NVH evolution**, where the objective is to understand how changing tooth geometry over life alters excitation and noise behavior. This use case is highly relevant in practice, especially where tonal problems emerge or intensify after running time rather than in the nominal new condition. Yet it remains one of the least mature commercially integrated workflows. The core difficulty is iterative: geometry changes, contact changes, excitation changes, dynamic response changes, and potentially acoustic outcome changes must all be tracked across life states. Some commercial ecosystems contain pieces of this chain, especially where tribology, durability, or tolerance logic is present, but the open literature still suggests that full wear-to-radiation workflows are limited and unevenly demonstrated.

For this reason, the best current software strategy for wear-driven NVH studies is often not a single platform but a **research-oriented coupled workflow**. Tools with strong contact and geometry-handling logic may be used upstream, while dynamic and acoustic environments are used downstream for selected life states. This is a technically meaningful use case, but it cannot yet be treated as equally mature to classical nominal TE analysis or standard subsystem vibration studies.

6.9. Early Concept Studies and Architecture-Level Trade-Off Assessment

Not all gearbox NVH questions require detailed tooth contact or radiated-noise fidelity. In early development phases, the dominant need may be **architecture-level trade-off assessment**, packaging logic, system interaction, controls coupling, or first-order driveline vibration feasibility. In such cases, early-stage system tools such as GT-SUITE and Simcenter Amesim can be especially valuable. Their main advantage is speed and breadth rather than local geometric detail. They allow rapid integration of multidomain subsystems and can support early decisions before detailed 3D contact and structural models are available.

These platforms should therefore not be judged by the standards of LTCA software or structural-acoustic FE solvers. Their role is different. They are best used when the development team needs to identify broad risk regions, compare architectures, or establish cross-domain consistency early in the process. Their limitation is obvious: they are not a substitute for detailed excitation modeling or final radiated-noise prediction. But their strategic importance is often underestimated precisely because they solve a different class of engineering problem.

6.10. Practical Recommendations by Use Case

Taken together, the comparison leads to several practical recommendations. **Dedicated gearbox CAE tools** are generally the most suitable first choice for gear-mesh excitation prediction, TE-focused studies, and microgeometry optimization. **General MBD platforms** are the strongest choice for subsystem-level dynamic transfer analysis, flexible-body interaction, and drivetrain response problems. **Integrated multiphysics and structural-acoustic environments** are the most appropriate for housing-response and radiated-noise studies where acoustic fidelity is central. **Early-stage multidomain tools** are best suited to architecture-level screening, electrified system integration, and rapid concept comparison. In many industrially relevant workflows, the most effective strategy is not to force a single environment to answer every question, but to combine categories according to where each is strongest.

Table 3. Typical engineering use cases and most suitable software categories.

Engineering use case	Most suitable software category	Why this category fits best	Typical secondary / supporting category
Gear mesh excitation prediction	Dedicated gearbox CAE	Native support for LTCA-like contact logic, TE, mesh stiffness, and	General MBD for downstream response

		microgeometry sensitivity	
Transmission error and mesh-stiffness studies	Dedicated gearbox CAE	Fast and contact-centered engineering iteration	Multiphysics FE only for special high-fidelity confirmation
Microgeometry optimization	Dedicated gearbox CAE	Efficient repeated evaluation across many geometry variants	Simcenter / Ansys / MBD environments for downstream confirmation
Gearbox / subsystem transfer-path analysis	General multibody dynamics platform	Strongest for shafts, bearings, splines, flexible-body interaction, and resonance-sensitive response	Dedicated gearbox CAE upstream for source definition
Flexible-body drivetrain response	General multibody dynamics platform	Flexible-body formulations are central to subsystem response fidelity	Structural FE environment for detailed local confirmation
Housing vibration studies	Integrated motion-structure or multiphysics environment	Structural interpretability and local modal behavior become decisive	MBD environment for upstream loading context
Radiated-noise prediction	Integrated structural-acoustic / multiphysics environment	Direct access to structural-acoustic and radiation modeling	Embedded-acoustic gearbox workflow for early screening
Electrified drivetrain / e-axle NVH	Hybrid chain: dedicated gearbox + MBD + multiphysics, or broad integrated ecosystem	Multi-source and multi-domain coupling makes single-layer workflows less sufficient	Early-stage multidomain tools for concept phase
Manufacturing deviation / measured flank studies	Dedicated gearbox CAE as entry point, then hybrid chain	Geometry-centric platforms are the natural starting point, but full propagation remains uneven	Multibody / acoustic environments for downstream selected cases
Wear-driven NVH studies	Research-oriented coupled workflow	No uniformly mature single-category solution identified in open evidence	Contact tool upstream + MBD / acoustic tools downstream

Early concept / architecture screening	1D / multidomain system simulation	Fast cross-domain integration and early trade-off assessment	Detailed gearbox or structural tools later in the process
Digital-twin-oriented workflow development	Broad integrated ecosystem plus measured-data-aware coupling	Requires workflow continuity more than any single isolated solver	Validation-focused hybrid chain

7. Current Gaps and Limitations

Despite the clear progress of commercial software ecosystems, the present review shows that the field still contains several important unresolved gaps. These limitations do not imply that current platforms are inadequate. On the contrary, many are highly capable within their intended scope. The problem is that gearbox vibroacoustic simulation is often discussed as if software packages offered uniformly mature, end-to-end predictive chains, whereas the available evidence suggests a more uneven reality. The main limitations concern **validation depth, workflow continuity across solver layers, measured-geometry integration, wear-driven simulation**, and the persistent gap between **documented capability** and **independently demonstrated predictive maturity**.

7.1. Limited End-to-End Validation from Tooth Contact to Radiated Sound

The most important current limitation is the scarcity of openly documented, independently validated workflows that cover the **full chain** from tooth contact and transmission error through dynamic transfer paths to housing vibration and radiated sound. The literature contains many strong studies on individual layers of this chain. Contact analysis and transmission error are well established. Flexible multibody validation studies also exist. Structural-acoustic studies of gearbox radiation are likewise available. However, fully integrated validations that connect all these layers in one consistent commercial workflow remain much rarer.

This matters because errors can accumulate across interfaces. A contact model may predict TE credibly, yet the mapping of that excitation into a dynamic model may simplify stiffness, damping, or local flexibility. A multibody model may reproduce subsystem response trends, yet the reduced structural representation may omit critical housing modes. A structural-acoustic model may be physically rich, yet the upstream loading may not reflect the true measured excitation with sufficient accuracy. In other words, good performance at one solver layer does not automatically guarantee end-to-end predictive reliability.

For this reason, one of the central conclusions of this review is that many current workflows should still be interpreted as **partially validated chains**, not as universally proven excitation-to-radiation solutions. This is particularly important when software is used for absolute radiated-noise prediction rather than for ranking, comparison, or trend interpretation.

7.2. Uneven Maturity Across Solver Layers Inside the Same Ecosystem

A second major limitation is that software ecosystems are often strongest in one or two methodological layers, but are not equally mature across all of them. Dedicated gearbox tools remain particularly strong in contact, load distribution, TE, and microgeometry iteration. General MBD tools remain especially strong in subsystem dynamics, flexible-body interaction, and transfer-path representation. Multiphysics FE environments remain strongest in structural-acoustic depth. The recent trend toward broader, more integrated ecosystems is real, but it does not eliminate these asymmetries.

This has a practical consequence: a software package may advertise a broad workflow range, yet some parts of that range may still rest more on architectural potential or recent feature additions than on extensive peer-reviewed validation. That does not invalidate the capability. It simply means that breadth of workflow and maturity of evidence must not be conflated. This distinction is especially

important in radiated-noise, e-drive, and manufacturing-aware workflows, where vendor-facing capability expansion has advanced faster than the open validation literature.

7.3. Persistent Interoperability Challenges for Measured Manufacturing Deviations

A third major limitation concerns the treatment of **measured geometry**, especially measured flank topography, CMM-derived deviations, and manufacturing-related surface variation. From a physical and industrial standpoint, this area is highly important. Real gearbox NVH is influenced by manufacturing scatter, assembly effects, and surface deviations that are not fully captured by nominal geometry. Yet software maturity in this domain remains uneven. Some platforms clearly support microgeometry definitions, tolerances, or imported deviation concepts. However, robust, standardized, and transparent propagation of measured flank topography through the entire contact–dynamic–acoustic chain is still not a uniformly mature commercial reality.

The difficulty is not only geometric. It is also methodological. Measured data must be mapped onto analysis-ready surfaces. The resulting deviations must alter contact in a stable and physically meaningful way. Those changes must then propagate into dynamic loading and, ideally, into system-level NVH prediction. Each step introduces assumptions, preprocessing choices, and potential uncertainty. This is why manufacturing-aware NVH simulation remains one of the clearest examples where software capability should be discussed in graduated terms rather than binary labels.

7.4. Immature Wear-Driven NVH Workflows

The treatment of wear-driven NVH evolution remains another major unresolved area. This limitation is especially significant because many tonal issues either emerge or become more severe only after running time, rather than in the as-new state. From a physics perspective, wear-driven NVH requires repeated update of geometry, contact conditions, excitation, and dynamic response across life states. In principle, the necessary building blocks exist across current software categories: contact solvers, durability-related modules, dynamic solvers, and structural-acoustic tools. In practice, however, the open evidence for robust, commercially mature end-to-end workflows remains limited [15].

This does not mean wear cannot be studied. It means that wear-informed NVH usually still behaves more like a **research workflow** than a standardized industrial push-button process. Analysts often have to assemble the chain manually, select representative life states, or rely on partial coupling rather than continuous automated evolution. This is one of the clearest frontiers where academic research remains ahead of everyday software standardization.

7.5. Gap Between Vendor-Documented Capability and Peer-Reviewed Evidence

A further structural limitation of the field is the gap between **what software is documented to do** and **what has been demonstrated publicly in peer-reviewed work**. This gap should not be interpreted suspiciously by default. Commercial tools are often used in proprietary industrial workflows that are never published in full detail. Nevertheless, for a critical review, the distinction remains essential. Official documentation is appropriate for identifying supported modules, release features, and solver families. It is not sufficient on its own to establish predictive maturity across all use cases.

This issue is especially relevant in areas such as embedded acoustics, digital-twin-oriented workflows, e-drive NVH integration, and manufacturing-aware simulation. Vendors may document these capabilities credibly, and they may indeed work effectively in practice, but the open literature often provides only limited independent comparison or validation. As a result, one of the responsibilities of a review article is to prevent the reader from confusing **feature availability** with **broadly demonstrated performance**.

7.6. Scarcity of Direct Software-to-Software Benchmark Studies

Another limitation is the lack of direct, neutral **software benchmark studies**. The literature contains abundant method papers and many application papers, but far fewer studies that evaluate multiple commercial platforms on the same problem under comparable conditions. The study by Bejar et al. is therefore especially valuable, precisely because it provides one of the relatively rare examples in which software choice itself becomes the object of technical comparison.

The absence of more such studies has two consequences. First, it makes it harder to distinguish general methodological strength from software-specific tuning or workflow craftsmanship. Second, it increases the burden on reviewers to synthesize evidence indirectly from separate studies, each with its own assumptions, geometry, loading, and validation scope. This does not make comparative review impossible, but it does require caution. The present article therefore avoids simplistic software rankings and instead emphasizes category-level suitability and evidence maturity.

7.7. Trade-Off Between Speed, Integration, and Physical Depth

Commercial software also remains constrained by a persistent engineering trade-off between **computational speed, workflow integration, and physical depth**. Dedicated gearbox tools are often highly efficient for repeated contact and microgeometry studies, but they may require additional environments for high-fidelity housing radiation questions. Multiphysics FE environments can be physically richer for structural-acoustic analysis, but they are typically less efficient for broad variant sweeps. MBD platforms occupy an important middle ground, especially for dynamic subsystem behavior, but may depend on upstream contact models or simplified loading abstractions.

This trade-off is not a defect of any single platform. It is intrinsic to the problem. Yet it does explain why no software ecosystem has fully removed the need for task-aware workflow design. In practice, “more integrated” does not always mean “more accurate for every purpose,” and “more detailed” does not always mean “more useful at the decision point that matters.”

7.8. Incomplete Maturity of Fully Coupled Electro-Mechanical-Acoustic Workflows

Electrified drivetrains intensify another major limitation: the incomplete maturity of **fully coupled electro-mechanical-acoustic simulation**. In e-axles and other compact electrified systems, tonal outcomes can depend on gear excitation, housing dynamics, bearing paths, electromagnetic forcing, and inverter-related content. Commercial ecosystems increasingly acknowledge this, and several now present workflows that connect mechanical and electrical domains more explicitly. However, the open evidence still suggests that fully validated, routine end-to-end workflows spanning all these interactions are not yet uniformly mature.

This limitation is especially important because electrified drivetrain NVH is one of the fastest-growing application areas for current software. It is therefore likely to remain a key driver of future software development, but at present it should still be treated as an area of active convergence rather than complete methodological closure.

7.9. Limited Standardization of Evidence Reporting

A final limitation is the lack of standardized reporting practices across software-related NVH studies. Different papers report different validation targets, different error measures, different operating conditions, and different levels of model disclosure. Some focus on TE correlation, others on housing acceleration, others on internal dynamic force, and others on radiated sound. This heterogeneity makes the literature richer, but it also makes cross-study comparison more difficult.

For future software-specific reviews, it would be highly beneficial if publications more consistently stated which layer of the chain was validated, which software layers were involved, which quantities were measured, and where the main modeling assumptions entered. Until such reporting becomes more standardized, synthesis will continue to rely partly on interpretive judgment rather than direct one-to-one comparison.

7.10. Summary of the Current Limitations

Overall, the current limitations of gearbox vibroacoustic software are not best described as simple missing functions. They are better understood as **maturity mismatches across workflow layers**. Contact-side modeling is relatively mature. Dynamic subsystem modeling is also comparatively mature where flexible-body methods are used carefully. Structural-acoustic prediction is physically rich but often heavier and less widely validated in complete coupled workflows. Measured-topography handling, wear-driven NVH, and fully integrated electro-mechanical-acoustic prediction remain the least uniformly mature areas.

Table 4. Major current limitations and unresolved gaps across software platforms.

Limitation / gap	Most affected category or layer	Why it remains unresolved	Practical implication
End-to-end validation from tooth contact to radiated sound	All categories, especially across coupled chains	Individual solver layers are better validated than their interfaces	Absolute acoustic prediction should be interpreted cautiously
Uneven maturity within broad software ecosystems	Broad integrated commercial suites	Workflow breadth can grow faster than peer-reviewed validation maturity	Capability lists should not be read as equal proof across all layers
Measured flank topography / CMM interoperability	Dedicated gearbox workflows and hybrid chains	Requires robust geometry mapping and stable downstream propagation	Manufacturing-aware NVH remains less standardized than nominal analysis
Wear-driven NVH simulation	Cross-category research workflows	Iterative geometry-contact-response update remains complex and unevenly automated	Often still a research workflow rather than a routine industrial chain
Gap between vendor-documented capability and peer-reviewed proof	All commercial ecosystems	Proprietary industrial workflows are seldom published comprehensively	Reviews must separate feature availability from demonstrated maturity
Scarcity of direct software-to-software benchmarks	Entire field	Neutral benchmark studies are rare	Category-based assessment is often more defensible than simple ranking
Trade-off between speed and physical depth	Especially between dedicated gearbox tools and multiphysics FE tools	Fast workflows and high-fidelity structural-acoustic workflows optimize different priorities	Hybrid strategies remain common and often necessary
Fully coupled electro-mechanical-acoustic maturity for e-drives	Broad integrated ecosystems	Mechanical, electrical, and acoustic layers are converging, but open	E-axle NVH still benefits from layered

		validation remains selective	toolchains and careful scope control
Limited standardization in validation reporting	Literature and software evidence base	Different studies validate different outputs with different disclosure levels	Cross-study comparison remains partly interpretive

8. Future Directions

The future development of gearbox vibroacoustic software will likely be driven less by the invention of entirely new physical principles than by the **better orchestration of existing solver layers**, combined with more realistic data integration and stronger validation practice. The current landscape already contains many of the required building blocks: contact analysis, transmission-error prediction, flexible multibody dynamics, structural-acoustic simulation, and optimization frameworks. What remains incomplete is their consistent, efficient, and transparently validated integration across real industrial workflows. For this reason, the most important future directions are expected to emerge at the interfaces between methods rather than within any single method alone.

8.1. More Credible End-to-End Excitation-to-Radiation Workflows

A first priority is the development of more credible and more openly demonstrated **end-to-end workflows** linking tooth contact, transmission error, dynamic force transmission, housing response, and radiated sound. Commercial ecosystems are already moving toward broader internal continuity, especially in Romax, Simcenter, MASTA, and Ansys-related chains. However, the literature still indicates that end-to-end predictive maturity is less established than capability breadth. A key future direction is therefore not merely adding more modules, but validating the interfaces between existing modules more systematically and publishing those validation results more transparently.

This has an important practical implication. The next generation of useful software advances may not come primarily from more detailed TE plots or more detailed acoustic meshes in isolation, but from better confidence that a change observed at the contact level remains physically meaningful through the downstream structural and acoustic chain. That kind of confidence is essential if commercial software is to move from relative ranking toward stronger predictive decision support.

8.2. Stronger Integration of Measured Geometry and Manufacturing Reality

A second major future direction is the deeper integration of **measured geometry**, including CMM-based flank topography, production scatter, and as-built rather than purely nominal gear states. The technical motivation is clear: real gearbox NVH is affected by manufacturing variation, and the current generation of software still handles that reality unevenly. Future progress will therefore depend not only on broader geometry import support, but on more standardized and robust mapping from measured surfaces to analysis-ready contact models and onward to system-level NVH predictions.

This direction is likely to reshape both software design and validation practice. Once measured deviations are integrated more routinely, model validation can move beyond nominal benchmark cases and toward population-aware or tolerance-aware predictive studies. That would be especially valuable for electrified drivetrains, where narrower acoustic expectations and stronger tonal exposure make manufacturing scatter more consequential.

8.3. Wear-Informed and Lifecycle-Aware NVH Simulation

A third future direction is the maturation of **wear-informed** and more broadly **lifecycle-aware** NVH workflows. At present, wear-driven vibroacoustic simulation remains closer to a research frontier than a routine industrial standard. Yet the importance of this topic is likely to increase, because many tonal problems become more evident after running time, and electrified drivetrains may further increase sensitivity to geometry evolution over life. Software ecosystems that can update

tooth geometry iteratively, re-evaluate contact and excitation, and propagate those changes into structural and acoustic response will become increasingly valuable.

This direction also connects naturally to durability and digital-twin thinking. However, the technically meaningful future is not generic digital-twin terminology by itself, but concrete workflows in which evolving geometry, measured behavior, and validated system response can be linked with sufficient transparency and computational efficiency. That remains an open challenge, but it is one of the clearest long-term differentiators for future software ecosystems.

8.4. Broader Electro-Mechanical-Acoustic Coupling for E-Drive NVH

Electrified powertrains will continue to push software development toward stronger **electro-mechanical-acoustic coupling**. Gearbox NVH can no longer be treated as an isolated mechanical subproblem when the final tonal character may depend on the interaction of gear mesh harmonics, electromagnetic forces, inverter-related content, structural transfer paths, and radiation behavior. Vendors have already started adapting their ecosystems to this reality, but the future need is not merely coexistence of electrical and mechanical modules; it is their more credible and better validated coupling under realistic e-axle operating conditions.

This trend is likely to favor software families that can either span multiple domains internally or connect them reliably through hybrid workflows. It may also increase the importance of architecture-level multidomain tools, because many electro-mechanical trade-offs emerge before final 3D NVH models are stabilized. In that sense, the future of e-drive NVH software will probably be more layered, not less: concept tools, contact tools, dynamic tools, and acoustic tools will need to communicate more effectively across project phases.

8.5. Faster Acoustic Prediction Without Abandoning Physical Interpretability

Another likely future direction is the continued development of **faster acoustic prediction methods** that preserve useful physical interpretability. Recent vendor moves toward embedded or accelerated acoustic workflows suggest that industrial users increasingly want earlier access to sound-related outputs rather than waiting until late, heavy FE/BEM studies. This pressure is unlikely to disappear. Instead, it will probably increase as optimization, architecture exploration, and tolerance studies require more acoustic awareness at earlier design stages.

The key challenge will be balance. If reduced-order or embedded acoustic methods become too detached from structural-acoustic reality, they risk becoming convenient but insufficiently trustworthy. If they remain too computationally heavy, they lose their practical advantage. The most valuable future development is therefore not simplification alone, but **well-calibrated simplification** with clearly stated scope and validation boundaries.

8.6. Optimization Under Uncertainty Rather than Nominal-Only Optimization

Optimization itself is also likely to evolve. Historically, much gearbox optimization has focused on nominal geometry refinement, especially at the microgeometry level. The next step is likely to be more widespread **optimization under uncertainty**, where the objective is not only to improve nominal TE or nominal vibration response, but to improve robustness against tolerances, assembly variation, and operating variation. Recent software developments already suggest movement toward stronger optimization and variation-aware workflows, but the future opportunity lies in combining these with more realistic manufacturing and system-level uncertainty models.

This direction is particularly important for industrial NVH, because customer-perceived acoustic quality depends on population behavior rather than on the single best nominal model. Software ecosystems that support robust optimization and uncertainty propagation efficiently may therefore become more valuable than those that only offer high-fidelity single-case analysis.

8.7. Better Evidence Reporting and Software-Aware Validation Culture

A further future direction concerns not software capability alone, but the **culture of evidence reporting** in the field. As long as publications continue to validate different quantities under inconsistent reporting practices, software-specific comparison will remain harder than it needs to be. Future studies would benefit greatly from clearer statements about which layer of the chain was modeled and validated, which software environments were used at each stage, which quantities were measured, and where the main assumptions or reductions entered.

Such reporting would not only improve academic transparency. It would also strengthen industrial transfer, because it would help engineers distinguish between validated predictive pathways and workflows that are still promising but less mature. In effect, the future of software-specific review depends partly on future studies being more explicit about software architecture, coupling logic, and validation scope.

8.8. Practical Outlook

Overall, the future direction of gearbox vibroacoustic software is likely to be defined by **convergence with selectivity**. Platforms will continue to broaden, but not all of them will become equally strong in every layer of the chain. Instead, leading ecosystems will likely distinguish themselves by how effectively they combine source fidelity, system-level dynamics, acoustic accessibility, optimization efficiency, and measured-data realism for particular classes of engineering problems. The most successful future software strategies will therefore probably be those that make hybrid workflows more transparent, more automatable, and more convincingly validated, rather than those that simply claim universal coverage.

9. Conclusions

This review has shown that the software landscape for gearbox and geared-drivetrain vibroacoustic simulation is best understood not as a single competitive field of interchangeable tools, but as a **layered ecosystem of partially overlapping solver philosophies**. Dedicated gearbox CAE platforms remain strongest where the dominant task is tooth-contact analysis, transmission error prediction, mesh-stiffness evaluation, and rapid microgeometry iteration. General multibody dynamics platforms remain strongest where the key challenge is subsystem or drivetrain-level dynamic transfer, flexible-body interaction, and resonance-sensitive response analysis. Integrated multiphysics and structural-acoustic environments remain the most powerful when housing vibration and radiated sound are central targets. Early-stage multidomain tools remain highly relevant where architecture-level speed, cross-domain integration, and concept screening dominate the engineering need.

A central conclusion of the review is that **software choice materially shapes the simulation outcome** even before the analyst reaches full-system NVH. Differences in contact modeling assumptions, flexibility treatment, solver coupling, and structural-acoustic depth can alter predicted excitation, dynamic transfer behavior, and radiated-noise interpretation. This point is supported both by the limited but important benchmark literature and by the broader methodological separation that still exists between excitation-focused, response-focused, and radiation-focused workflows. As a result, no serious software-specific review can treat gearbox NVH platforms as simple front ends to the same underlying analysis logic.

The review also confirms that recent commercial development has moved clearly toward broader and better-connected workflows. Since 2023, major platforms have expanded support for electrified drivetrain NVH, optimization, tolerance-aware simulation, embedded or accelerated acoustic workflows, and tighter continuity between gear-design and system-level modeling environments. These developments are technically meaningful and reflect real industrial demand. However, they should be interpreted as **convergence without full equivalence**. The breadth of a software ecosystem does not automatically imply equal maturity across all layers of the excitation-transfer-radiation chain.

The most important unresolved limitation remains the relative scarcity of openly documented, independently validated end-to-end workflows from tooth contact to radiated sound. Contact-side modeling is comparatively mature. Flexible multibody dynamics is also well established when applied carefully. Structural-acoustic simulation is physically rich and increasingly accessible. Yet the open evidence for fully validated commercial chains that robustly connect all of these layers remains thinner than software capability descriptions might suggest. This is especially true in measured-topography integration, wear-driven NVH evolution, and fully coupled electro-mechanical-acoustic workflows for electrified drivetrains.

From a practical engineering standpoint, the review therefore supports a **task-based software selection strategy** rather than a search for a universally superior tool. For concept-level studies, early-stage multidomain platforms are often the most efficient choice. For gear-contact-focused studies and microgeometry optimization, dedicated gearbox CAE tools remain the most natural first environment. For subsystem dynamic response and transfer-path problems, multibody dynamics platforms are generally the strongest choice. For high-fidelity housing-response and radiated-noise studies, structural-acoustic or multiphysics environments remain indispensable. In many real industrial workflows, the most effective solution is a deliberately structured hybrid chain rather than a forced single-software workflow.

Looking ahead, the most valuable future progress is likely to come from better interface quality between solver layers, stronger integration of measured geometry and manufacturing reality, more mature wear-informed workflows, and more transparent validation practices. In that sense, the future of gearbox vibroacoustic software is not simply about adding more features. It is about making hybrid, multi-layer simulation chains more trustworthy, more efficient, and more clearly validated for the engineering decisions they are meant to support.

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