NVH Analysis Techniques for Design and Optimization of Hybrid and Electric Vehicles
Conclusions & Next steps

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Conclusions

COST Action TU1105 started in April 2012 with the ambition to engage Noise, Vibration and Harshness (NVH) experts from vehicle industry and renowned research groups in the accumulation, development and dissemination of novel techniques for the analysis, design and optimization of hybrid and electric vehicles. Driven by a socio-economic quest towards developing transportation with lower CO2 emission, as a global goal of the EU and a crucial ingredient for the competitiveness of the whole European transportation industry, automotive industry substantially increased its focus on such alternative powered vehicles. To be competitive, however, they must have an acceptable NVH behaviour, not only inside the vehicle, but also outside if it is nor to pose major concerns regarding safety of weaker road users such as two-wheelers and pedestrians. As most of the vibro-acoustic design and problem-solving knowledge gathered has concentrated on internal combustion vehicles, TU1105 studied the correlation between the existing analysis techniques and the requirements coming from alternative powered vehicle technology.

TU1105 activities were coordinated with and bootstrapped on EU research initiatives such as FP6 CALM (Coordination of European Research for Advanced Transport Noise Mitigation); FP6 CANTOR (Coordinating noise transportation research and engineering solution); FP7 CO2NTROL (Integrated solutions for noise and vibration control in vehicles); FP7 MID-MOD (Mid-frequency vibro-acoustic modelling tools - Innovative CAE methodologies to strengthen European competitiveness) and on EU research and training initiatives focussing on Early-Stage Researchers such as FP7 GRESIMO (Best Training for Green and Silent Mobility); FP7 eLiQuiD (Best Engineering Training in Electric, Lightweight and Quiet Driving) and FP7 ANTARES (Advanced Training and Research in Energy Efficient Smart Structures). Furthermore, TU1105 partners used their roles and networks within relevant automotive associations such as ERTRAC (The European Road Transport Research Advisory Council), EUCAR (The European Council for Automotive R&D), CLEPA (The European Association of Automotive Suppliers) and EARPA (The European Automotive Research Partners Association) to feed in industrial requirements and state-of-the-use automotive technologies and at the same time to disseminate TU1105 results.

This final book report, summarizes the work performed within the Action, highlighting challenges originating from the use of alternative powertrains, discussing potential solution technologies (some of them breakthrough innovations at the verge of industrial demonstration) and defining fields of future research for which research and innovation activities are needed in the very near future to ensure that European automotive industry is able to keep its prime NVH position and can keep on developing vehicles combining both excellent customer comfort with safe mobility solutions, and this considering ecologic and economic constraints.

Whereas chapters 1 and 2 set the scene, in describing human expectations with respect to alternative powertrains and discussing in detail various possible alternative powertrains and their NVH implications, chapters 3, 4 and 5 discuss innovative solution technologies to bridge some of the identified gaps:

- Chapter 3 gives an overview of innovative experimental NVH analysis techniques to be used in the study of alternative powertrains. Ten subsections discuss in detail work on TPA/OPA, virtual sensing approaches, vibro-acoustic characterisation approaches for lightweight materials, inverse methodologies for low-frequency transmission loss characterization, equivalent material modelling, NVH investigations of hybrid urban buses, electric vehicles in noise maps, innovative noise measurement methods, advanced multi-axial dynamic testing and monitoring of rotational dynamics systems.
- Chapter 4 focusses on simulation approaches for NVH analysis and is built around five cases: the design and validation of a metamaterial acoustic enclosure, the development of motion equations of mechanical systems, the numerical prediction of the sound field produced by EVs, multiphysical modelling of SRM motors and the use of element-based simulation techniques for design and validation of warning sound devices.
- Chapter 5, finally, discusses the subjective perception of EV related NVH issues and focusses both on interior noise analysis due to electrification of vehicles and warning sound analysis and their detectability towards vulnerable road users.

The above chapters present important achievements, as well as suggestions for future work in their respective domains. The suggestions for future work are also grouped and discussed in more detail in the next section.

Next steps

The TU1105 COST Action provided the unique opportunity to bring together experienced academic and early-stage researchers, EU authorities for transport regulations, independent consultants, experienced representatives from industry and associations of transporters in the field of NVH of alternative powered vehicles to brainstorm on emerging requirements for novel tools and methodologies. This networking think-tank resulted in a detailed analysis of existing approaches for NVH analysis as well as validating them with respect to the emerging requirements of alternative powered vehicles. From this, and together with the Task Force NVH of

EARPA (The European Automotive Research Partners Association), the following NVH Research Needs, Priorities and Challenges are identified as crucial for automotive engineers to design and build vehicles for the next generation:

- **Test and simulation tools for NVH design, analysis and optimization** of vehicle components/systems and their integration. As time is lacking to build up NVH experience for novel powertrain solutions (it has taken over 50 years to develop for this for ICE NVH), an urgent need for new NVH tools is arising, especially for novel NVH source components such as electro-motors, range extenders, gears and power electronics. Breakthrough innovations developed over the past years in (academic) research environments hold huge potential to completely change the analysis/design/optimization of the NVH behaviour of tomorrow's vehicle. Hybrid Numerical-Experimental approaches such as virtual sensing and Design approaches coming over from software-design such as Model-Based System Engineering provide the inspiration and the building blocks in upgrading NVH from a performance attributed often assessed late in the design process when first prototypes become available, to a true design attributed included frontloaded to early design stages.
- **Material technologies for both noise and vibration mitigation** try to reduce (annihilate) the impact of noise and vibration sources from the vehicle and its components. Recent advances in manufacturing, material science, electronics and control engineering pave the way towards the development and deployment of a next generation of smart materials solutions: passive solutions such as new metamaterial concepts hold potential for developing very NVH performing, yet low-weight structural components; advances in both mechatronics (actuator and sensor design) and control engineering make actively controlled materials reality; new physical insights and supporting CAD/CAE tools allow including final product noise and vibration behaviour already in conceptual design phases; etc.
- **Symbiotic technologies for NVH adaptation** hold great potential in improving the NVH behaviour of full vehicles and individual components. With the growing technological complexity of modern systems, also the availability of inherently present (electronic) intelligence follows. Resulting in vehicles with embedded sensors, actuators, control units, CPUs, etc., typically not for NVH purposes, but for safety, performance, comfort and entertainment. By exploiting the already available technologies in a symbiotic manner, the NVH behaviour can be adapted, opening up a completely new range of applications: exploiting (distributed) powertrain components as inherent NVH sensors/actuators for reducing noise and torsional vibration levels without adding additional systems nor material; optimizing (semi-)autonomous and assisted driving scenarios to positively influence overall urban noise levels; deploying existing entertainment systems in combination with distributed vehicle vibration sources (such actuators and switches) to optimize the interior NVH experience for the driver and passengers; etc.
- **Customer and road user NVH perception** is still mostly assessed based on engineering biased dB(A)-based metrics, although many have shown that

these do not suffice to fully capture subjective NVH perception. Novel comprehensive, cost functions are needed to include not only the 'engineering' levels of noise and vibration, but also aspects from human and environment. Such new cost functions will allow for more general road noise assessment and feed also new developments in Vulnerable Road User (VRU) protection for quiet vehicles.

- **Future infrastructure developments** have a major influence on environmental noise evolution. The idea of just reduction of urban noise is now in conflict with safety aspects associated to VRU navigation in cities. Thus a new concept of urban noise design should be considered based on the idea that future cities can have noise maps that are created by managing quiet vehicles with directive warning signals for pedestrians together with generalised use of directive acoustic sources on building façades and other urban furniture sources to generate low, but detectable sound levels suitable for pedestrian navigation safety and urban sound-scape definition. Outside urban areas, technologies are needed to further reduce noise disturbance by tackling both the source (e.g. sustainable low-noise pavements, low-noise tyres with low rolling resistance yet adequate grip) and the transfer path (advanced infrastructure solutions – e.g. intelligent/active/unobtrusive noise barriers).

TU1105 partners and stakeholders will bootstrap on the above identified topics for future research and innovation and will find each other in new project and network initiatives continuing the work and as such contributing to the TU1105 Action legacy.