Platform development for HEV & EV
Frontloading NVH brings benefits to FutureSteelVehicle
Commissioned by WorldAutoSteel, a consortium set up to promote the use of steel in the Automotive industry, the FutureSteelVehicle (FSV) project set out to highlight the potential of advanced steel technology in vehicle body designs of the future by developing a concept vehicle platform to suit a range of alternative powertrain configurations.

The challenge set by WorldAutoSteel was to design a concept vehicle which was of low mass, the target body in white (BIW) mass for the battery electric vehicle variant was <190kg, while maintaining functional performance levels expected from a car today.

LMS provided the noise vibration & harshness (NVH) engineering expertise for the concept design phase of the project at the request of WorldAutoSteel. A holistic multi-attribute approach to the vehicle and body concept design was desired, this included front loading NVH engineering to prove that a lightweight vehicle concept could successfully achieve the multi-functional performance expected of a modern automobile (crash, comfort, noise etc.) while reducing body mass.

Opinions within the auto industry agree that NVH will remain a critical customer issue for electric vehicles. “It would be wrong to assume that the electric motors are completely quiet. Quite the contrary is true, in fact. Depending on the design of the motor, the electromagnetic (EM) pulses and corresponding torque pulses from the motor can be very strong. These can be radiated as noise directly from the motor housing and can also be transmitted to the support structure through the motor mounts.”

Achieving low body mass and good NVH performance at the same time is perceived to be a contradictory objective. For crash, the reconciliation comes from the extensive use of High Strength Steels (HSS) and Advanced High Strength Steels (AHSS), which bring a good crashworthiness to the FutureSteelVehicle while allowing for thinner gauges. In NVH, using thinner gauge materials usually has a negative impact on NVH behaviour; therefore the challenge was to propose a clever body design which strikes a balance between low mass and acceptable NVH performance.

LMS Engineering Services carried out the NVH simulation studies on the FutureSteelVehicle project in close collaboration with the consortium performing the crash and rigidity studies. The fact that the NVH was front loaded in the holistic approach adopted by WorldAutoSteel allowed significant improvement to be made from an NVH perspective while not hindering progress towards the low body mass targets. Overall the final body concept was 35% lighter than the benchmark platform the FutureSteelVehicle was evaluated against, demonstrating steel technology as an excellent choice for meeting stringent body mass reduction targets in a green vehicle context and front loaded NVH as a benefit to platform concept design at an early stage.
While electric vehicles are perceived to be, and indeed are quieter than those with an internal combustion engine (ICE), during operation they produce noise at frequencies which are well above the norm for automotive applications. There is an expectation that pure tone high frequency noise emitted by electrical components will be a nuisance to NVH engineers as the peaks will be significantly above the background sound level in the high frequency range. These high frequency tones will adversely affect the comfort and experience of the passengers. It was important to ensure that the FSV Body concept design was tailored to eliminate these effects sufficiently by optimizing the sound package.

Before the design could be refined, however, targets for acoustic performance had to be set. To this end a benchmarking exercise was carried out. A small vehicle platform (referred to as the target class A/B Small EV or ICE), which uses the same body for both ICE and EV powertrains was loaned from a prominent OEM. This vehicle is within the same vehicle class as the proposed FutureSteelVehicle. Benchmarking was carried out to highlight the differences between the acoustic signatures of the ICE and EV variants and provide targets for the FSV concept design to be evaluated against.

Physical measurement and analysis revealed that the noise emitted by the electric motor powered vehicle was significantly less than the ICE powered equivalent, Figure 1 demonstrates this. It also highlighted that there was a distinct, prominent pure tone peak on the EV in the high frequency range, this related to the number of poles within the electric motor (referred to hereafter as np) which provided an unpleasant listening experience at order 4x np. Reducing the prominence of this peak was identified as a hurdle to overcome in the concept of the FSV body design as it would result in a better overall NVH performance than the benchmarked target Class A/B small EV.

The results indicated though that significant savings in weight might be achieved with clever design due to the quieter drive train in an EV by relaxing the NVH upper target limits in the frequency range <1kHz, for example body noise transfer function (BNTF) between the motor mounts and the passenger cabin could have their upper limit raised without impairing whole platform NVH targets.
Design Refinement, using NVH analysis to positive affect body mass reductions

Low frequency targets for BNTF were set at 60dB, a relaxed value to take into account the relative quietness of the EV. The results showed that while the FSV was within a few dB of this target it was still 10dB quieter overall than the target class A/B ICE vehicle.

In the mid frequency range it was initially assumed that panel vibration was the most effective focus point for NVH improvements. The project demonstrated, however, that work on the transmission path of vibrations (i.e., on the body parts between the motor mounts and the radiating panels) was more effective than panel design, intervening closer to the source. For example, attempts at preventing the transmission of vibrations by the front longitudinal member or the cowl top proved to be effective, a 1.4kg weight saving in panel gage reduction was gained for a 150g increase in the cowl top reinforcement by doubling the gage to reinforce the connection to the A pillar proved that focusing on the transfer path is more effective than treating the radiating panels.

Also in the mid frequency, the use of vibration damping steel (VDS) in specific areas was shown to be an effective solution providing additional mass savings without NVH compromises when compared to traditional damping alternatives. Vibration Damping Steel (VDS) is an interesting prospect as a lighter solution than glued treatments: it comprises two steel sheets sandwiching an intermediate layer of polymer, in the order of 40 microns thick (dimensions of each layer can be varied to suit the particular application), hence of negligible mass, and with a sufficient loss factor. Application of this material varies with body design, in the case of the FSV the use of VDS in the dash panel proved to be the most effective, reduce transmitted noise without weight penalty.

The high frequency pure tone noise generated by the electric motor is a problem that will be faced by the NVH departments of automotive manufacturers now and in the future. By their nature they can easily be controlled with absorption materials but the penalty is generally a mass increase. LMS engineers used the Tone to Noise Ratio (TTNR) and Prominence Ratio (PR) to analyse and quantify the problem on the FSV. These figures for sound quality assessment are becoming more widely considered for EV applications as they allow engineers to focus on the detail of the sound quality. It was expected that a 3dB reduction of the prominent frequencies could be obtained for a penalty of around 1kg in weight, which is small in comparison to savings elsewhere in the sound package.
Conclusions

At the beginning of concept design the BIW mass of the EV was over the 190kg target, however, by the final iteration it had been exceeded, with a saving of 14.6kg achieved between the beginning and the end of the concept design phase. Importantly the NVH performance was shown to positively contribute to the concept body design and mass reduction program by identifying and analysing specific areas where performance was beyond the targets set and mass could be reduced. LMS Engineers were able to use LMS Virtual.Lab to simulate design changes as the design team were working on them, at this early stage in the concept design process, significant design changes could be made to reduce NVH issues without increasing the mass as the design, simulate and analysis activities were carried out in a balanced iterative loop.

The FSV exceed the targets set by the benchmarking process, on top of that it was found that FSV did not require glued damping treatments to attenuate motor noise, saving 3.6kg due to the use of VDS which contributed to the 14.6kg total BIW mass saving achieved between the beginning and the end of the concept design phase. The use of vibration damping steel could be a permanent addition to the NVH engineers’ toolbox in years to come as the technology advance; it highlights the innovativeness of steel in terms of green concepts in vehicle design.

The culmination of this work is that the concept was considered to be ready for prototyping and validation activities. This would provide the information to judge the effectiveness of the analysis in a full vehicle development cycle.