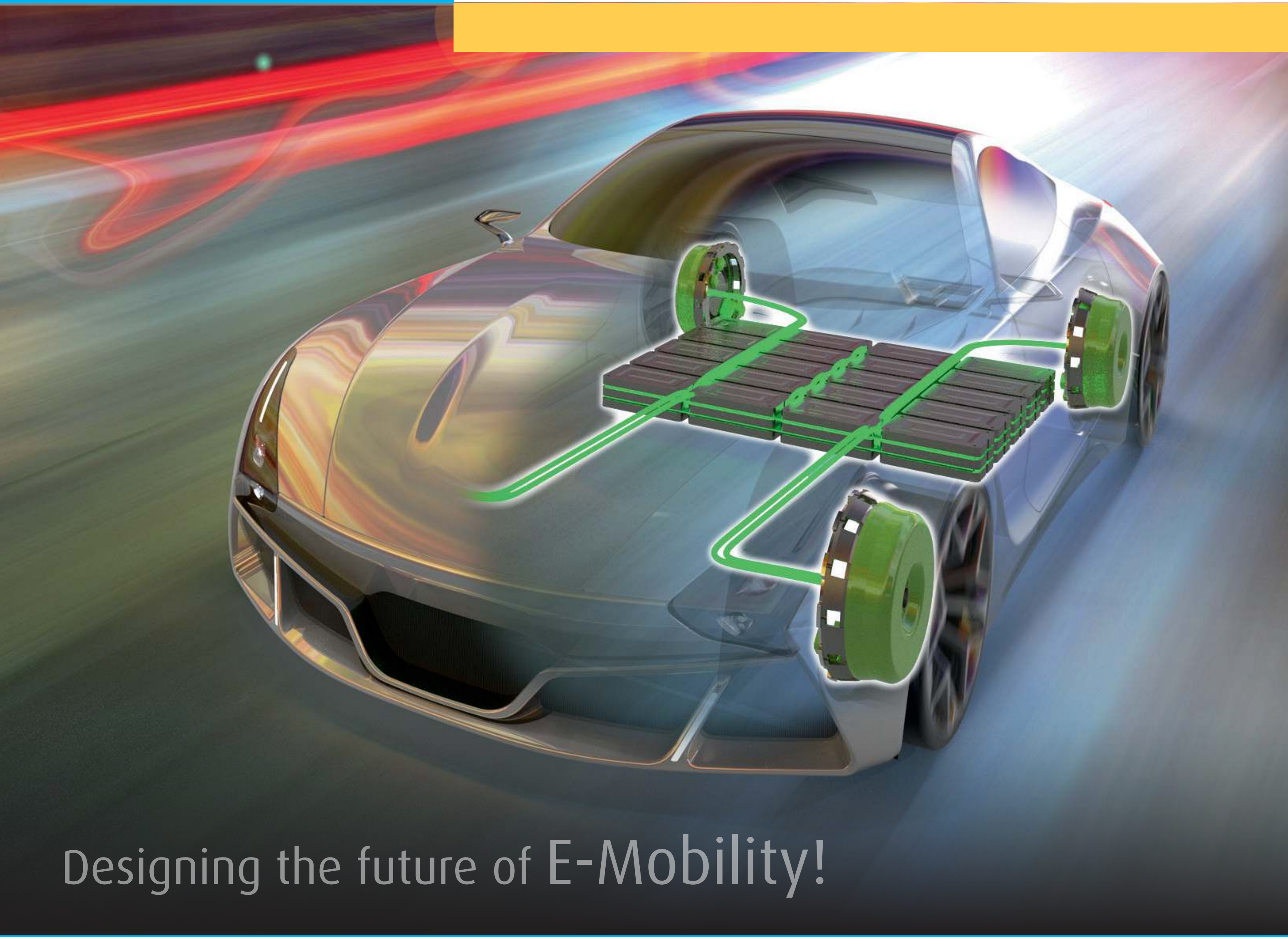
Altair

SIMULATION-DRIVEN INNOVATION™



Designing the future of E-Mobility!

ELECTRIC VEHICLES

Accelerate Decision Making using **Simulation-Driven Design**

Electric Vehicle is a Reality!

Increased push from governments to reduce emissions has accelerated the rate of XEV (Hybrid Electric Vehicle) development across the globe. Government of India's impetus on electric vehicles has motivated OEMs in the Indian automotive space to earnestly invest in this domain. Even though it is said that pure EVs have fewer moving parts, the challenges of designing an efficient machine actually goes up many fold. A normal ICE vehicle is well understood from technology, product design, integration, validation and market (customer) perspective. An electric vehicle just destroys all the base.

There are some key challenges that have to be addressed while designing an EV when compared to a conventional nternal Combustion Engine (ICE) Vehicle:

- **The battery pack is generally twice as heavy compared to a conventional powerpack for the same vehicle. This implies the vehicle will be heavier if not properly designed and optimized.**
- **The batteries and other components produce significant heat which needs to be managed as it could drag the performance down.**
- **Even though the electric motor is more efficient, design and optimization of such a motor is complicated due to the multi-physics nature of the machine.**
- **EVs need to be continuously monitored for performance and adjustments done in microseconds or less to ensure losses are minimized and performance maximized.**
- **Physical Prototyping and Testing time and cost can be significantly higher due to additional requirements.**

EV is a machine with disparate pieces of technology coming together to work efficiently. To develop such a vehicle, it necessitates leverage of simulation and design optimization technology that offers several technology pieces and the cross interaction under one platform. Altair HyperWorks™ is a single platform solution for XEVs.

Figure 1 shows a classic V diagram used in design and development. Altair has technology and processes at all stages of the V. While it is

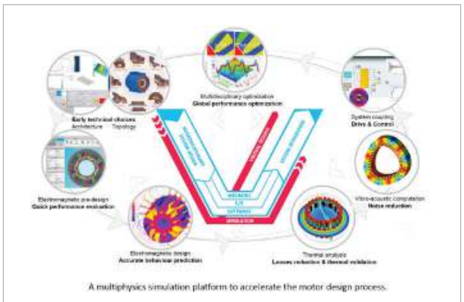


Figure 1: Classic 'V' diagram

an accepted fact that simulation is an important tool in the design, development and validation process of a vehicle to reduce cost and time (Altair customers have reported an average time and cost savings of 15 - 30 %), it assumes an even more significant role in the design cycle of an electric vehicle. Most product companies would like to reduce cost of design and development and improve the certainty and efficiency of performance. System efficiency should be understood as efficiency of each system separately like mechanical, electrical, etc. and together as one. This is where Model Based System Design (MBSD) comes in. Interestingly, the challenges listed above also fall in the distinct domains of Mechanical, Electrical and Electronics part of an EV.

This write up attempts to elucidate the challenges involved in design and validation of EVs and how simulation and design optimization solutions offered by Altair play a vital role in addressing them to deliver optimum results in performance, speed, time and cost. This is relevant for both OEMs and suppliers alike.

Mechanical: Range and Lightweighting Aspects

Any discussion on Electric Vehicles is incomplete without a mention of Range Anxiety. There is a well-established connection between range and lightweight. The power and torque requirement from the prime mover are directly influenced by the weight of the vehicle. This dictates how much energy from power source is needed. If weight is reduced, there will be less demand on the energy and thus for a given energy source, the range improves with light weight.

For Altair, simulation technology and optimization technology is a key enabler for achieving lightweight designs which eventually helps to get a better range. Altair not only has relevant technology but also relevant process to achieve lightweight designs.

The lightweighting technology from Altair is available for two main stages of product design, i.e. concept stage and detail stage; for single part or a large system like a complete BIW (Body-in-White); for SDO and MDO (single disciplinary and multi-disciplinary optimization); for conventional metals and new age materials like composites; for most commonly used manufacturing process like stamping, casting and injection molding; with bespoke process called C123 for new architecture/ platform development and variant derivation. Altair has complementary technology to help get the right loads for lightweighting.

Altair OptiStruct™ (an industry pioneer in simulation driven optimization) has already helped several industries to achieve lightweight designs. The same technology is also made available to the designer community for generating and validating design early in the concept stage with Altair Inspire - used

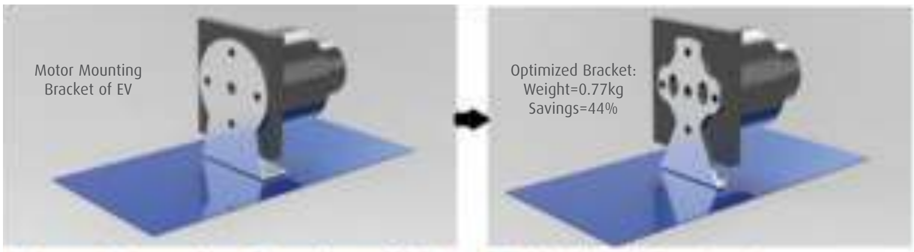


Figure 2: Altair Inspire – Combines Motion, Structure and Design Generator in a single intuitive environment

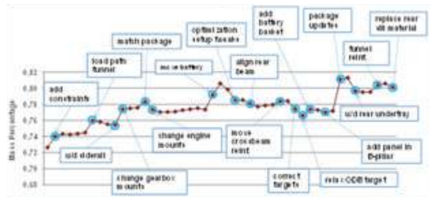


Figure 3: Mass deltas - likely in EV design

for components and systems alike for attaining early design directions. Customers have reported upwards of 10% weight savings and doubled design space exploration by using optimisation driven design approach early in the design cycle. One of the interesting outcomes also happens to be part count reduction during the process of lightweighting, again enabled by Altair OptiStruct.

Here are a few examples/applications that showcase what can be done leveraging the depth and width to achieve lightweighting.

- **How to generate design guidance upfront in the design cycle?**
- **Can it be used when the 3D CAD is not available?**

Figure 2 shows how Altair Inspire™ can be leveraged to generate designs of motor mounting brackets of EV using motor torques and self-weight and do verification analysis, all in one environment. No 3D CAD from designer is taken as input.

EVs have very different aggregates such as traction motor, inverter, electronics and batteries, which dictates that the packaging be redone. How to derive multiple variants or how to derive a common platform? Altair's C123 process can answer questions like:

- **How to decide the best possible structural layout of the BIW of EV to satisfy various performance requirements like Safety, Strength (durability), Stiffness (NV)?**
- **What should be the ideal section geometry to retain the known performance metrics as well as new ones, like protection of batteries during impact situations?**
- **Where should the cross members be placed to protect the battery in its casing?**

Obviously, the existing process is quite time consuming to resolve these issues. Altair's C123 can carry out optimization driven-simulation driven design for BIW. It is designed to generate quick results to answer questions from the designers, program managers and even vehicle line executives. OEMs have reported 15% reduction in weight and 25% reduction in cycle time on a new vehicle platform leveraging C123. Figure 3 shows answers to what-if scenarios at the concept design phase with results producted in as fast as 30 minutes.

It is anticipated that EVs will be using a lot of lightweight parts and this will drive multiple efforts along improving existing designs and/or searching for alternative materials. For example, using composites as a material of choice for components like bumpers, B-Pillar reinforcements, cross beams, other inserts can help reduce weight by 30-40%. Altair OptiStruct simulation technology can be used to design and optimize both short fibre composites and long fibre composites. Glass Fibre Reinforced Plastics (GFRP) and Carbon Fibre Composites are the most likely candidates for EVs. Crashworthiness (safety) can be particularly challenging while engineering with composites. Figure 4 shows a study carried out to replace steel crush-can with a composite crush-can leveraging Altair technology. OEMs have been able to achieve 5 - star rating for crash and safety using Altair Radioss™.

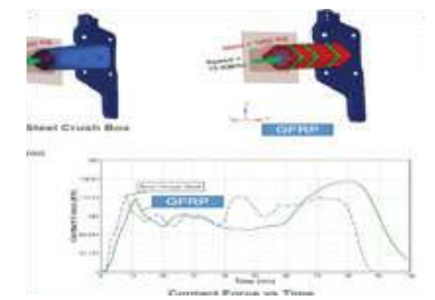


Figure 4: Steel ▸ composite crush-can enables lightweight

Altair's lightweight technology is ideal for enhancing range of EVs. It not only helps achieve weight reduction but also ensures fulfilling desired performance criteria for EVs. The technology lends itself to be used by suppliers and OEMs alike. Starting early with optimization driven designs can reap higher benefits.

Mechanical: Range and Thermal, Fluid Aspects

The key element of an EV is the battery, and its performance is sensitive to temperature. Batteries also produce heat during their charge-discharge cycle. A similar issue of heat (unwanted) exists in Motors, Inverters and other Power electronics in EV. An efficient thermal management system (TMS) is of paramount importance to ensure optimal performance and/or prevent degradation of life and hence, range. The Battery TMS impacts cost, life and range of the EV. Some interesting questions that can arise here are:

- **What is the best suited TMS for Indian conditions?**
- **How do you convert an active cooling system to an equivalent passive cooling system or the other way around depending on market requirements?**
- **Is a passive cooling system really capable of doing the job, given that temperatures during Indian summers can easily touch dangerous levels for the battery? Did you know the battery life drops by 50% at 40ºC!**
- **What are the sensitive parameters in a TMS and what questions can be answered without having to string a pack and test it in a lab?**

A battery TMS study or an EV TMS study involves the use of thermal and fluid physics and Altair's AcuSolve™ (Computational Fluid Dynamics based simulation technology) is best suited to carry out this study. Consider an example of a battery cell shown in the Figure 5 (next page) - a typical 18650 cell. Details of the number of modules considered, is given in the figure.

Both active cooling system, using Ethylene Glycol (50:50) as a coolant, and passive cooling system, using air as the medium, were studied in steady state and transient conditions. A constant heat flux value was assumed in both the cases to decide on the flow rate of the liquid coolant and air. The model had upwards of 40 million elements. Some of the useful outputs from this work are shared below. Altair AcuSolve, Altair Activate™ and Altair HyperStudy™ are ideally suited for design study and optimization of battery TMS and TMS in general.

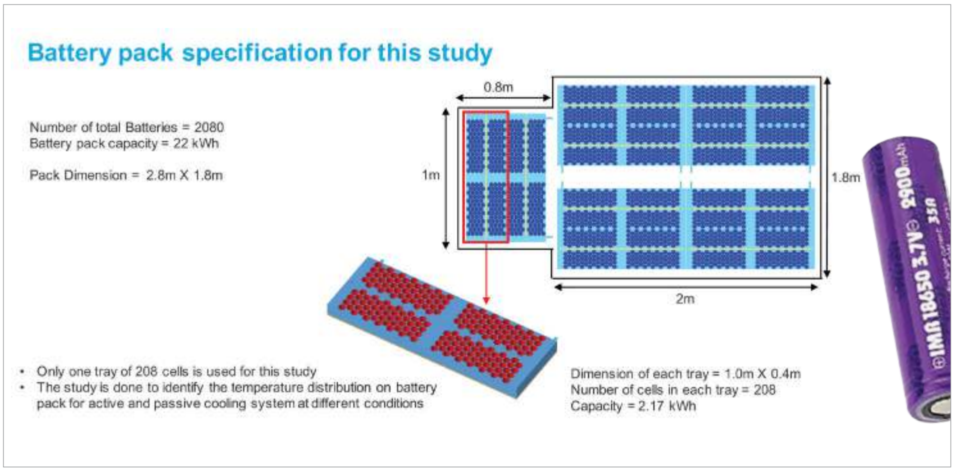


Figure 5: Sample setup of Battery Thermal Management Simulation using AcuSolve

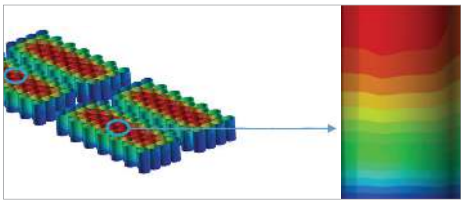


Figure 6: Overall temperature distribution in the battery module and in a single cell

The delta or temperature difference was found to be 6.1ºC. The industry requires this to be as small as possible. Design ideas were tried to reduce this temperature difference. Cell spacing was observed as a key parameter to make the TMS efficient. But this would affect packaging, weight, etc. This study has revealed that TMS design is a complicated affair and can be both

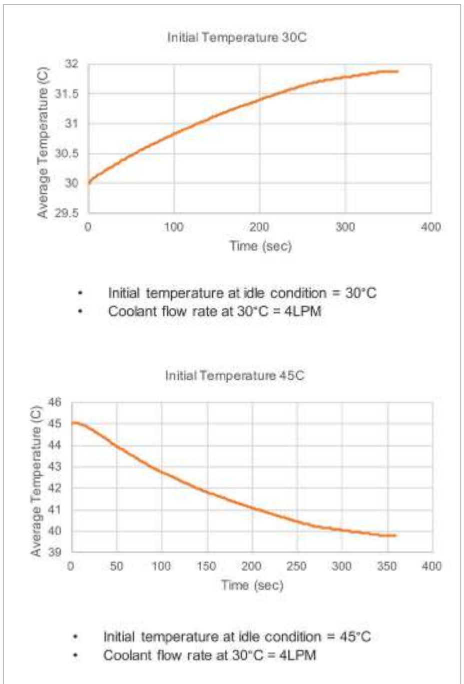


Figure 7: Stabilization patterns that are likely in EV Battery TMS

time consuming and costly. Simulation technology is the key to keep costs down and accelerate design maturity. Parameters such as flow rate, temperature profile, pressure drops, HTC (heat transfer co-efficient), power required to pump the coolant and CoP can be calculated easily.

- **How important is pre-cooling for Indian conditions? Take a look at Figure 7.**

Power required in general, higher ambient conditions, and integration with other systems are some of the parameters that are likely to incur a penalty in case of passive cooling in Indian conditions. This is only indicative, and such data would be crucial to carry out trade-off studies. Since the TMS consumes power, the power needs to be minimized to keep the battery operating at the right temperatures. This implies that TMS has to be developed in conjunction with battery supplier, BMS supplier and with the OEM. Altair AcuSolve – Thermal and CFD simulation technology - helps achieve this complex task.

Aerodynamic forces at high speeds are also a cause for concern from range perspective. Drag or simply wind resistance, is one of the important parameters that is studied during the design stage. The vehicle has to use available power to overcome wind resistance. Without getting into the mathematical relations, the chart in Figure 8 indicates how the wind resistance can increase four folds as the drive transitions from city to highway conditions. AcuSolve based Virtual Wind Tunnel is a utility developed to do quick studies to understand what kind of drag forces can be expected based on the styling or to evaluate what the drag could potentially be for few styling concepts. The key here is speed. VWT can evaluate wind resistance and provide feedback to the stakeholders within an acceptable time.

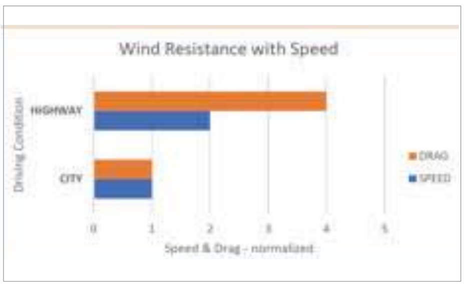


Figure 8: Wind Resistance (Aerodynamic Drag) between city and highway driving

The two concepts shown in the Figure 9 were created to ascertain this and clearly indicate which one of them is more aerodynamic.

Figure 9: Two different styling concepts created to ascertain effect of drag

Altair's Thermal and Fluid solver technology is ideal for finding solutions for thermal management system and also minimizing wind resistance. It can be used for various flow situations encountered in automobiles viz. exterior, interior, under hood, underbody, etc., all relevant to EVs as well.

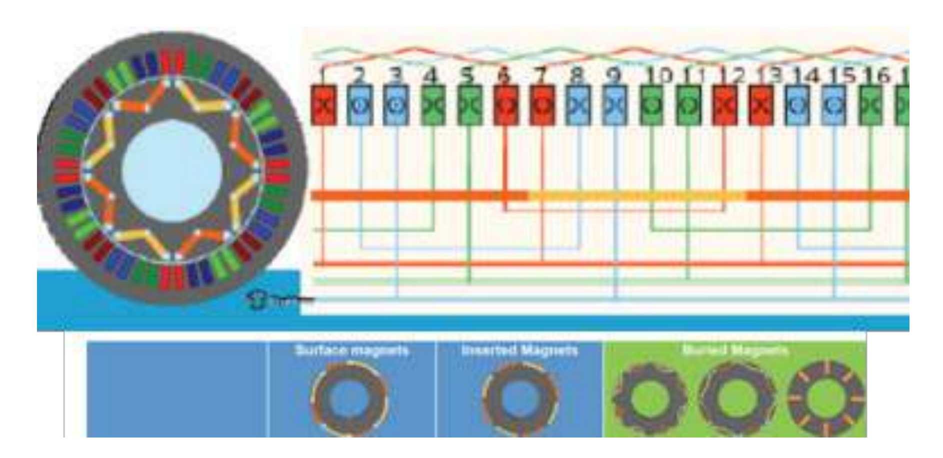


Figure 10: Quick design Studies using FluxMotor

Electrical: Range, Electro-Magnetics and Multi-physics Aspects

The next most important element of an EV is the traction motor. Traction motors are subject to extremely testing duty cycles and the design of these machines is also an arduous task. The multi-physics aspects involved makes it very challenging and time consuming. While sizing of the motor is not very difficult to do, designing a motor that is efficient, compact, lightweight, less demanding on TMS can be a tough task. This then is an excellent candidate for upfront simulation driven design. Altair's low frequency electro-magnetics solution enables design study and optimization of traction motors in an efficient manner. When it comes to traction motor, there are two main stages in design and development. One is the concept design stage and the other is the detailed design stage. PMSM motors are known to be the most compact, lightweight and efficient of the various types of motors known. A designer may ask:

- **How can one start designing a EV traction motor with just the performance curve in mind but no CAD?**
- **Is it even possible?**

Altair FluxMotor™ is an early stage design tool that does exactly that. It helps study different configurations of traction motor at a concept stage. It has a library of configurations of PMSM motors and is an open environment to take on more motor types and configurations. One can easily vary parameters such as number of stator slots, slot dimensions, number of rotor poles, magnet dimensions and position, winding topology, effect of changing the material of winding and other components; aiming to understand the performance like torque, power, maximum RPM, cogging torque, losses, torque ripple, etc. All these using a solver that has been developed over three decades with well established European industry partners! The assessment is done in less than an hour, in most cases 30 minutes. It is important to match the required performance envelope quickly so that the key design parameters can be arrived at.

For example, given below in Figure 11 is a torque envelope based on vehicle performance and specification. The main parameters of the motor have to be arrived at quickly so that enough time can be allocated to optimization of the motor parameters. Figure 12 shows I-d, I-q type of current maps.

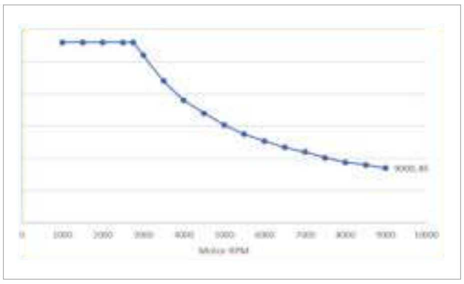


Figure 11: A typical traction motor torque – speed envelope

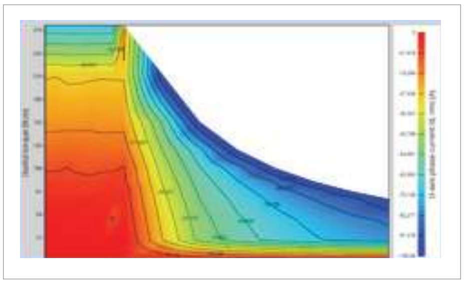


Figure 12: I-d, I-q type of current maps.

Magnet cost is a dominant factor in the total motor cost and it will be important to optimize the magnet mass to get the best torque density performance. Stator and rotor dimensions need to be optimized in addition to the windings to get the best power density. Any motor that increases operational cost or running cost because of sub-optimal efficiency is not a good motor even though it may meet mechanical performance requirements. Given that the cost of motor is significant, one would need several iterations to optimize and therefore, simulation driven design approach is the best method to cut down cost and time of optimization loop. It has been observed that efficiency range of 95 to 97% is achievable for motors at early design stage.

Once the early design is done using FluxMotor, the data can be exported to a more detailed Flux which is Finite Element based software. It not only allows to simulate electromagnetic performance of the motor but also looks at other multi-physics phenomena like noise induced by magnetic flux (vibro-acoustics) and heat generated during operation. Flux can also be co-simulated in a system model to devise control strategies and study system performance. For example, what will be the temperature increase in the motor for a given drive cycle? This will then help carry out cooling channel studies for the motor.

Some of the key uses of Flux for Indian market:

- **Change the maximum efficiency point to a desired speed level relevant to Indian market.**
- **Improve the efficiency of the motor from its current level.**
- **Keep the temperature in the motor to acceptable levels for Indian city drive cycle.**

A related paper titled "*Efficient System Modeling Accelerates Powertrain Electrification*" covers the traction motor design development in more detail.

Flux has the ability to carry out studies and optimization on all kinds of motors that are likely in an electric vehicle. For example: PMSM, Induction motors, BLDC, SRM, etc.

Careful design of the electrical machine is key to minimizing power consumption and maximizing performance. Altair's electromagnetics solver technology is great for XEV traction motor design study and optimization from both design and operational standpoint. The benefits can be reaped not only by motor companies, but also by OEMs.

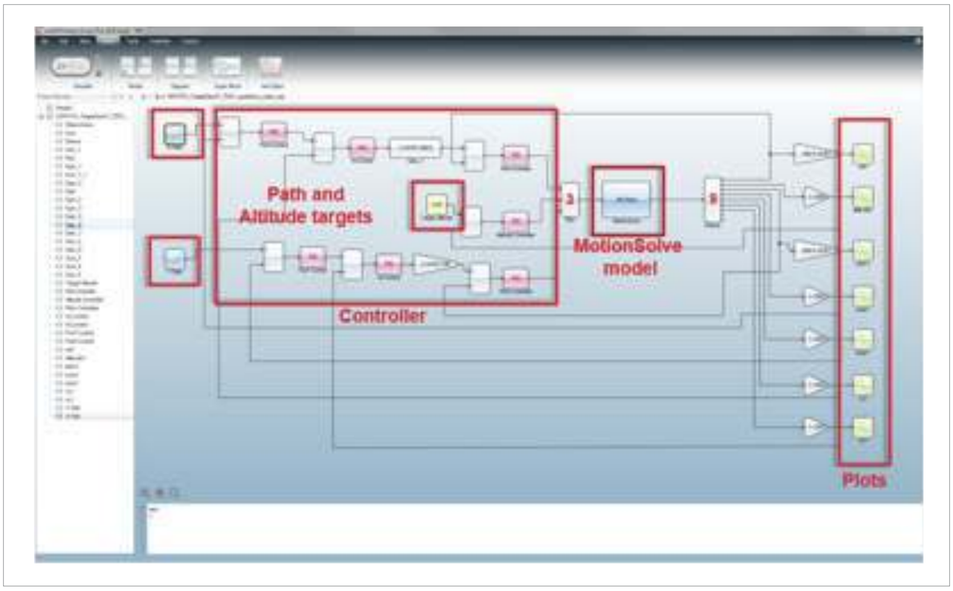


Figure 13: Altair's Activate – a Hybrid System Modeling Environment for Plant/Control Modeling and Co-Simulation

System Efficiency and Control: Multi-domain Aspects

Having the best battery or best motor approach may still not ensure the best vehicle. Designing an efficient vehicle calls for system study wherein various systems belonging to different domains are studied together to assess the system performance. This can then be optimized. Model Based System Design (MBSD) is ideally suited for this. Altair Activate and Altair Embed™ are relevant tools for MBSD.

The current generation of vehicles have ABS as a standard feature. EVs packed with electronics will try to bring in more mechatronic systems as a precursor to autonomous driving. Altair has relevant technology pieces for developing mechatronic systems like ABS, Adaptive Suspension, Steering controls and the likes. For example, multi-body based Altair MotionSolve™ can be used along with MBSD based Altair Activate and Altair Embed in a co-simulation mode. The MBSD platform allows math based system modeling, control systems logic design and fine tune systems even to the extent of reduced order hardware-in-loop (HIL) testing. Figure 13 above shows a sample co-simulation model where MotionSolve is co-simulated with control system model.

One can answer questions like:

- **What will be the stopping distance with and without ABS?**
- **Can the stopping distance be optimized even with ABS?**
- **What kind of stress differences do we observe with and without adaptive suspension?**
- **What is the SOC (state-of-charge) and FE (fuel economy) of a XEV given a drive cycle?**

Altair Activate has proven to be a powerful tool that provides effective system design and simulation solutions for multiple domains. It enables product creators, system simulation and control engineers to model, simulate and optimize multi-disciplinary systems. Altair Embed is a highly effective and quick diagram-to-autocode generation tool for developing control algorithms for e-mobility (motor-controls) and Battery Management System (digital power). It can be used for HIL, PIL and SIL validations and also to burn the code on to specified targets.

Complementary Section

One of the things simulation technology tries to do is to be generic enough to address the variety of needs depending on the product company. It is not uncommon in the space of EV for companies to try the retrofit route. Retrofit in the context of EV broadly means, taking out the fuel tank and IC engine and mount the battery and traction motor. This approach poses a few challenges, specifically on the weight side and therefore range side, and eventually has a potential to affect the warranty cost. Besides, the freedom of decision making is also likely to get impaired.

Altair's simulation technology can be used in situations such as retrofit as well. All the technology solutions discussed in earlier sections are applicable to retrofit situations too, but in a restricted sense. One interesting thing that we observed could potentially happen with retrofit scenario is shared here.

- **Can retrofit disturb the weight balance?**
- **Can a small change in weight balance in FAW/RAW cause a large change elsewhere? For example, changes could be understeer/oversteer, uneven tire wear, premature failure, etc.**

The battery pack is almost twice as heavy compared to a conventional power pack for the same vehicle. The weight balance between front and rear will get affected, and similarily the weight balance between left and right. Let us assume the base vehicle had a 50-50 split between FAW-RAW and after retrofitting the split becomes 47-53. It may seem a minor change, but actually it is not.

The best part of such simulation these days is that a lot of the work is automated and templatized to reduce the effort and more importantly to improve the velocity of decision making in a Product Design cycle.

Altair's multi-body technology was used to capture this scenario using a 4-poster setup. Figure 14 below shows the 4-poster setup.

Figure 15 on the right captures the percentage increase in load at key points of interest. By deploying simulation driven methods, one can quickly track the loads acting at various points and how is it affecting aspects of durability or drivability. In view of the aspect that the original vehicle may itself be a package of compromises, a compromise on compromise may not be a good choice. A company would not want customers to discover faults in its products - especially a customer who is accustomed to refinement of ICE vehicles and is betting on EV technology.

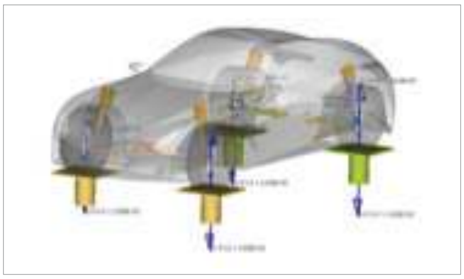


Figure 14: A 4-Poster setup to understand effects of retrofitting EV systems on existing vehicle

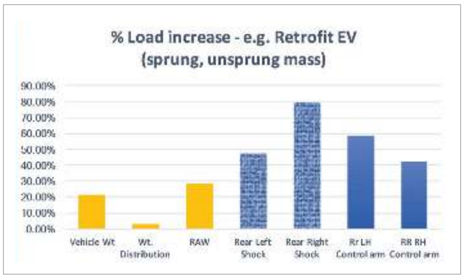
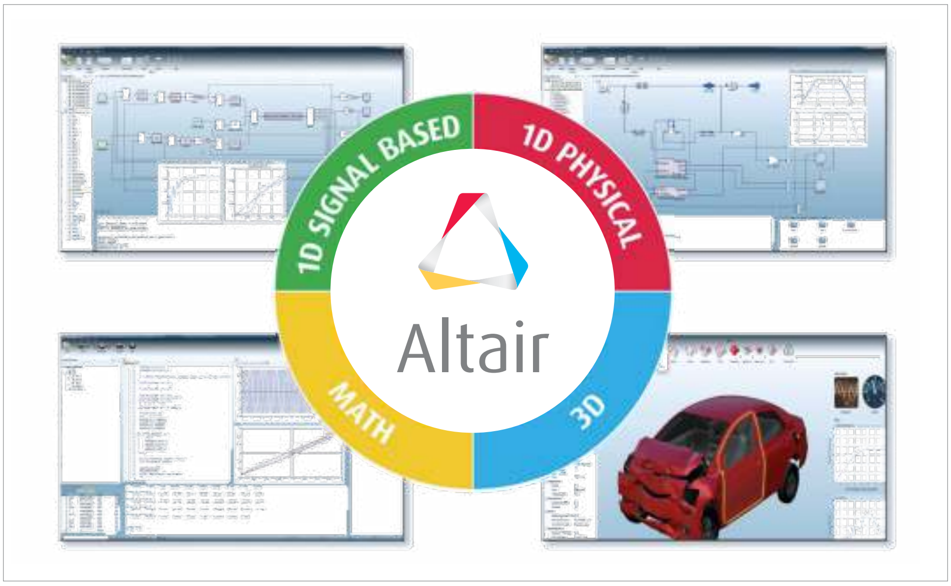


Figure 15: Percentage increase in load at key points of interest

Summary

To summarize, we have seen how Altair design and simulation technology can help address the challenges related to EV in distinct domains such as mechanical, electrical and electronics and vehicle as a system. Altair's broad and deep solutions span detailed 3D domains and now include 0D/1D math and system to help leverage the right tools to meet the challenge in designing electric machine with complex systems. Integration of these tools and others enables the Model-Based Design process to bring together the multi-domain teams needed to build the next generation of electrified vehicles. Also seen is how these solutions can be used for both ground up design and for retrofitting situations.



At Altair, designing a robust system is strategic to shape the future of e-Mobility. Representing all the key elements of the vehicle, from propulsion and energy management, to auxiliary ones like e-steering, e-throttle control, e-braking, and others, in the same model is the most efficient way to plug driving assistance layer. Once robust connectivity capabilities have been associated, it will lead the way to autonomous vehicles. More and more possibilities are available to help the designer be more efficient and accurate. Be it a supplier or a OEM, both stand to gain from these technologies.

A quick reference product list is given below to correlate the distinct areas of XEV and corresponding solutions offered by Altair

Product	Use	Product	Use
Altair Inspire	Early Stage Design Generator	Altair FluxMotor	Early Stage Motor Design and Optimization
Altair Inspire Studio	Surface (geometry) Creation	Altair Flux	Detailed Stage Motor Study and Optimization
Altair Activate	MBSD – System Modeling, Co-Simulation, FMU	Altair FEKO	Communication and EMC Compliance
Altair Embed	Embedded Systems, Digital Power Control	Altair Inspire Form/Cast	Forming/Casting Feasibility
Altair Radioss	Safety Regulations	Altair AcuSolve	Thermal Management System (Thermal, CFD)
Altair MotionSolve	Drivability & Durability; Right Loads for Lightweight	Altair OptiStruct	Lightweighting, NV, Durability
Altair HyperStudy	DOE, Optimisation and Robustness	Altair FrameWork	MDO, C123, VWT

Please write to **marketing@india.altair.com** to learn more

About Altair (Nasdaq: ALTR)

Altair transforms design and decision making by applying simulation, machine learning and optimization throughout product lifecycles. Our broad portfolio of simulation technology and patented units-based software licensing model enable Simulation-Driven Innovation™ for our customers. With more than 2,000 employees, Altair is headquartered in Troy, Michigan, USA and operates 71 offices throughout 24 countries. Altair serves more than 5,000 customers across broad industry segments.

Learn more at **altair-india.in**

Altair

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