WHITE PAPER

The Unified Frontier of Vehicle Safety Engineering

How Virtual Performance Simulation Accelerates the Innovation of Vehicles that Safely Move on the Ground, in the Air and in Orbit.

KEYSIGHT

Executive Overview

Safety engineers across different vehicle domains — ground vehicles, air vehicles, and space vehicles — stand to gain immensely from mutual learning and the exchange of insights as we advance into the era of CAE digitalization. This whitepaper explores the collective efforts of engineers dedicated to creating safer vehicles, regardless of the vehicle type, for our ever-advancing world.

We showcase real-world applications and the Return on Investment (ROI) that these technologies bring. We provide resources for those looking to dive deeper into this transformative field. Our primary audience includes automotive OEMs, tier 1 suppliers, automotive engineering consultants, CAE-specific specialists, and organizations within the crash and safety ecosystem.

Additionally, we address the heavy machinery sector, focusing on strength and dynamics.

Whether you are part of a safety system supply chain, involved in body and chassis production, seating and vehicle interior manufacturing, or work within suspension systems, this whitepaper offers valuable insights. It is equally relevant for technical buyers, influencers such as CAE Engineers, department heads for CAE, and specialists in 'Methods' departments who are responsible for evaluating new tools and methods.

Join us in exploring how virtual testing and simulation can support the development of safer, more reliable, and cost-effective vehicles, ensuring you stay ahead in this rapidly evolving industry.

Introducing the 4 Drivers of Change in Safety Engineering

Vehicle safety engineering is a multidisciplinary field that focuses on designing and implementing safety features in ground, aerial and space vehicles to reduce the risk of accidents and mitigate the severity of injuries in case of a collision.

This field encompasses various aspects, including crashworthiness, active and passive safety systems, strength & dynamics, and the integration of advanced technologies to enhance overall system performance. Mainly pioneered by ground vehicle manufacturers, the Research and Development (R&D) processes in vehicle safety engineering have been undergoing significant changes in recent years.

The growing complexity calls for a shift towards a more interconnected, data-driven, and simulation-based evolution of R&D processes in vehicle safety engineering. The goal is to create vehicles that are not only more crash-resistant but also equipped with proactive safety features and technologies that can adapt to changing driving conditions and user behavior. To achieve this effectively, engineers, regardless of the type of vehicle and their specific engineering domain need to collaborate, hence driving the implementation of end-to-end virtual prototyping.

4 Drivers of Change

Mainly pioneered by ground vehicle manufacturers, the Research and Development (R&D) processes in vehicle safety engineering have been undergoing a significant transformation in recent years. Discover the driving forces shaping the future of automotive safety and learn how authorities, consumers, OEMs, scientists, and IT professionals are catalyzing this change:

Authorities

Increasingly stringent safety regulations worldwide drive the development of new safety technologies. Vehicle manufacturers and suppliers need to collaborate globally to ensure compliance with diverse regulatory standards, leading to a more standardized and interconnected approach to vehicle safety.

Consumers

Today's citizens want sustainable mobility solutions from companies who act in a conscious, responsible way. In a nutshell: Consumers want the ultimate "ZERO": zero accidents, zero injuries, zero emissions, and zero unplanned stops with hours of charged, maintenance-free range.

Manufacturers

OEMs are looking for efficient R&D and production processes to deliver new mobility solutions quickly. The interconnected nature of engineering disciplines adds complexity on top of complexity, requiring OEMs to navigate these intricacies, introduce new technologies rapidly, and build trust in their performance throughout the product lifecycle.

Scientists & IT

Advancements in material physics, simulation and virtual prototyping technologies empower engineers to test safety features in a virtual environment, reducing reliance on physical prototypes. Large datasets incl. real-world driving data, AI, and enhanced data analytics enable a data-driven approach in R&D, allowing faster iteration and more precise testing e.g. of crash scenarios.

Goals in Safety Engineering

Engineers across all vehicle categories share similar goals. These include minimizing accident risks, optimizing vehicle structure for maximum strength, developing effective crash tests, and implementing advanced safety systems. These in themselves are complex tasks to achieve.

But as this wasn't complicated enough, safety and performance are often interrelated and interdependent in the design of any vehicle, be it for ground, aerial or space traffic. For example, enhancing robustness may increase the system's reliability in terms of crashworthiness and survivability, but also its complexity and weight, which may, on the other hand, reduce its agility and efficiency. Conversely, optimizing a vehicle for drivability, maneuverability, or speed may

compromise its durability or stiffness, which may increase its failure rate, downtime and overall vulnerability.

Therefore, vehicle safety engineers need to have early confidence in how their design affects both the performance and the safety of the system in order to make the right trade-offs with regards to business goals and constraints. In addition, driven by ground vehicle certification and homologation, virtual testing has been a goal for the manufacturing industry for quite some time. Ever increasing requirements from consumer protection and legal organizations are accelerating the pace for accepted procedures to use virtual testing as an alternative or supplement to physical testing and approval. However, progress in this area has been slow.

Let's look at some industry-specific goals for safety engineers:

Ground Vehicles

The ground vehicle industry requires perhaps less formal processes compared to the other two, though there is a significant focus on compliance and regulations. From vehicle design and crashworthiness to brakes and tires, CAE ensures the safety and reliability of all aspects of ground transportation to accomplish the overarching mission of achieving 'Vision Zero' for road casualties by taking action to improve the safety performance of on- and off-highway vehicles.

Aerial Vehicles

The aerospace industry has a strong certification and compliance requirement, with consequences on development cost and technology solutions. Safety is the overriding concern in aerospace and space technology. Countless test cycles, inspection procedures and certificates are behind every single part of the jigsaw. Although safety requirements are non-negotiable, they come at a cost – they slow down the speed of the product development cycle.

Spacecraft

To be absolutely safe, a system, product, device, or material should never cause or have the potential to cause an accident, a goal practically impossible to achieve. For such reason in the development and operation of space systems, the term "safe" means acceptable level of risk, relative freedom from, and low probability of personal injury, fatality, damage to property, or loss of critical equipment function, not absolute safety.

Regardless of whether on Earth or in space, engineers seek rigorous safety testing while striving to expedite design cycles and curtail costs by minimizing iterations and prototyping expenses. This layered complexity necessitates an efficient management of multidisciplinary challenges, requiring timely, collaborative decision-making.

The crux lies in achieving end-to-end digitalization across the product development cycle. However, despite the maturity of digital design tools and engineering simulation, their adoption remains limited to projects with substantial budgets and many companies lack the necessary capabilities despite recognizing their importance.

Safety Engineering Challenges

Whether on the road, in the air, or space, engineers face unique challenges. Ground vehicles must navigate safe road conditions, aerial vehicles must withstand extreme flight conditions, and space vehicles must endure the rigors of space. Despite these distinct requirements, a common trend across all vehicle engineering domains is the growing emphasis on virtual testing and simulation software. These technologies streamline the homologation process, reduce physical testing needs, and enhance overall safety.

Engineers working on crash, safety, strength and dynamics during new vehicle development need effective engineering analysis of emerging designs to ensure these designs meet safety regulations and offer optimal performance, quality, and reliability at minimal cost. The focus is on delivering accurate simulation results based on preliminary designs and refining these through subsequent design iterations, all while adhering to strict timelines and budgets.

Step change in vehicle design

The shift to electrified vehicles represents a dramatic change in vehicle design. Fast-evolving battery technology presents new, relatively unknown risks that must be managed. Additionally, the need for lightweight to improve EV range and compensate for heavy batteries drives the use of new materials and manufacturing techniques, such as giga castings, moving away from legacy approaches proven over decades. As we move towards automated vehicles, new challenges emerge, such as accommodating a wider variety of potential occupant seating positions in crash scenarios.

Increased focus on vehicle safety

Many manufacturers have adopted a ‘Vision Zero’ initiative, intensifying the focus on vehicle safety. This necessitates testing a broader range of crash scenarios, including those involving pedestrians and diverse population demographics. At the same time, regulations are becoming more complex, with tighter standards for battery safety and a growing prominence of active pre-crash safety systems, which influence crash behavior.

Virtual homologation

One of the most significant trends is the shift towards ‘Virtual Homologation.’ Bodies such as Euro NCAP are beginning to allow vehicle certification for specific crash cases through virtual assessment rather than traditional physical testing. As technology proves its capability to realistically simulate physical tests, more certification cases will move towards simulation. Virtual human body models are now so realistic that they can reveal the impact of a crash on the body more thoroughly than physical dummies ever could. This drives the need to ensure complete simulation accuracy and to perform many more simulations within available timeframes.

Cost and quality pressures

Increasing vehicle costs and market pressure compel OEMs to make electrified versions more affordable. This drives the need to reduce vehicle development and manufacturing costs, leading to new materials and manufacturing approaches. These bring new challenges in analyzing vehicle integrity and require CAE engineers to work as cost-effectively as possible. Customers also have

ever-increasing expectations for vehicle quality, dynamic performance, reliability, and refinement. OEMs must meet these demands to maintain brand reputation and sales levels. Safety engineers play a crucial role in achieving the right balance of these needs through their analysis activities.

OEMs Should Democratize Virtual Prototyping for Crash and Safety Engineering

Overcoming Major Challenges...

Reduce vehicle weight with suitable lightweight and recyclable materials due to the need to satisfy sustainable mobility demands and address EV range concerns.

Occupant safety is a critical design factor due to the unique safety challenges posed by new powertrain technology.

Profit margins are constantly under pressure due to high EV component costs, leading to customer concerns regarding the expensive prices. of electric vehicles.

Navigating uncertainties in battery innovation due to unknown factors in terms of performance, capabilities, and potential drawbacks alongside yet to be explored safety risks when pushing range limits.

...through End-to-End Virtual & Concurrent Engineering

Reduce development cost: Accessible virtual prototypes equipped with advanced machine learning, model-order-reduction and multi-domain analysis replace physical test and facilitate greater experimentation and design studies.

Innovate safety-compliant powertrain technologies: Industry-compliant assessment of occupant safety when incorporating electric powertrains and batteries, covering simulation f battery crash, crush, and shock as well as analysis of water ingress, moisture exposure, and safety of high-priority areas like the vehicle’s rear.

Balance performance, range and thermal safety: Digital battery analysis and a multi-scale modeling approach facilitate a wide range of assessments including vibration, swelling, short circuit, and fire safety.

Effective material exploration for optimal weight-strength: Fast, accurate solvers validate structural integrity of multi-material parts and effectively analyze scenarios like water crossing and intrusion by assessing the interaction between structures and fluids. Fast design iterations and modular material simulation models optimize material selection for vehicle use in terms of strength, sustainability, and suitability.

Take a Moment and Think about What the Response of Your Existing Engineering Approach is to Your Daily Work Challenges:

When being tasked to test a greater range of crash scenarios, can you do this in the same timescale?

Is it possible to automatically assess the quality of simulation models before solving them?

Can you predict connection breakage in early design stages when pushing the boundaries of lightweight design?

In the early stages of development, do you have all the confidence you need in the safe crash performance of batteries and novel lightweight materials?

Are you able to operate without the need for multiple expensive and time-consuming studies involving physical prototypes for validating and implementing countermeasures?

If just one answer is ‘no’, it’s really time to shift to a controlled VIRTUAL environment for evaluating vehicle performance, safety, and reliability in real-world operating conditions.

Virtual Safety Testing

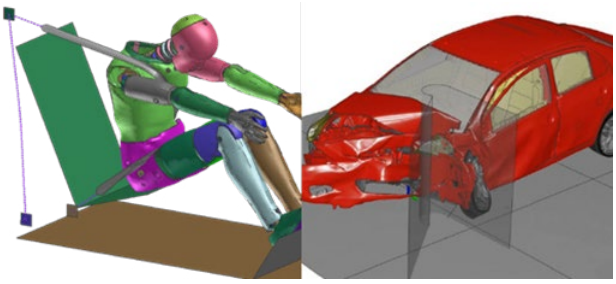
Virtual testing of vehicle performance has become crucial for some of the world’s most renowned brands in the automotive, heavy mobile machinery and aerospace industry. Through fully digital means, they achieve vehicle certification for crash, safety, and reliability for the first time without endangering humans or our planet.

Engineers need to be able to efficiently test all of the widely expanding diversity of use cases. Physical testing is not a favorable option due to its limitations when it comes to making design changes in the early development stages, which often leads to time-consuming modifications and delays in finalizing product design and launch.

Fully Digital in Ground Vehicle Crash & Safety Testing

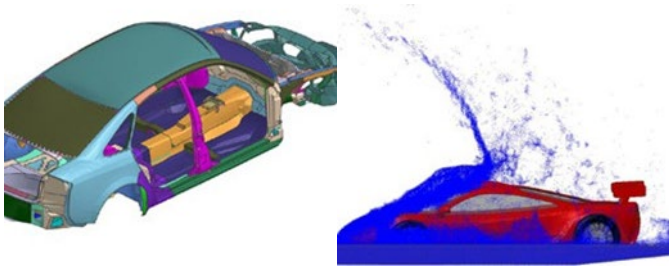
The core capabilities of virtual testing encompass comprehensive safety assessments, structural integrity analysis, seat and interior comfort evaluation, and system performance optimization for both highway and off-highway vehicles.

Crash & Safety capabilities include simulating vehicle crashes and developing airbag systems specifically for highway vehicles to assess their integrity and occupant safety. This includes analyzing the safety of both vehicle occupants and vulnerable road users during crashes. For both on-highway and off-highway vehicles, these capabilities extend to evaluating the safety and durability of vehicle batteries under various conditions.



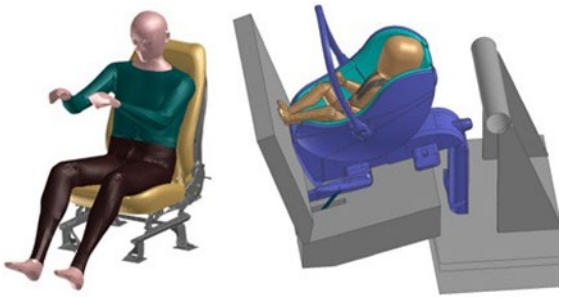
Crash & Safety analyses

Dynamics & Strength capabilities focus on assessing stress, strength, and misuse scenarios to ensure structural integrity for both on and off highway vehicles. Additionally, they test vehicle components for resistance to water ingress and management.



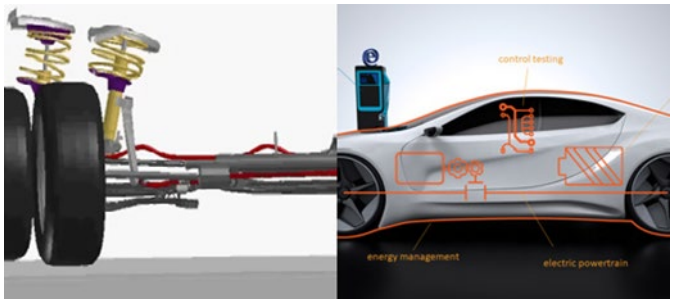
Strength & Dynamics validation

Seat and Interior simulation involve evaluating the comfort of seats and interior components under static and dynamic conditions, simulating whiplash scenarios to improve seat design and occupant protection, analyzing temperature regulation within the vehicle for occupant comfort, assessing the ergonomic design of vehicle interiors for optimal occupant comfort, and simulating the manufacturing process of interior trims to ensure quality and fit, all applicable to both on and off highway vehicles.



Seat & Interior comfort

System Performance capabilities include optimizing propulsion and transmission systems, hydraulics and pneumatics, vehicle dynamics, and electrification and energy management for both on and off highway vehicles.

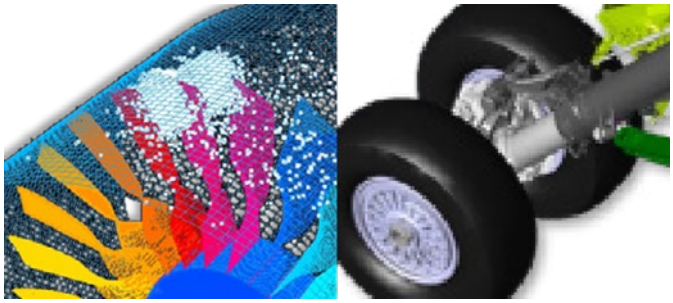


System simulation

Fully Digital in Aerial and Space Vehicle Crash & Safety Testing

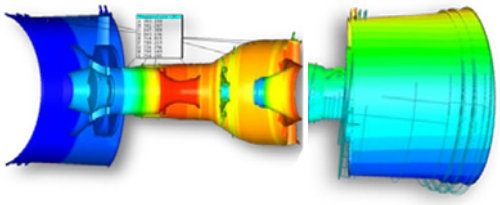
The core capabilities of virtual testing encompass comprehensive safety assessments, structural integrity analysis, seat and interior comfort evaluation, and system performance optimization for both highway and off-highway vehicles.

Crash & Safety for both, aerial and space vehicles, water ditching analysis is conducted for assessing emergency landing scenarios, while crash, impact, and HVI analyses are performed solely for space vehicles to ensure structural integrity. Shock analysis, AVA & Transonic Flow simulations, and Docking maneuvering are specific to space vehicles, ensuring safe navigation and component integrity during missions. Occupant restraint systems are also evaluated for space vehicles to ensure crew safety during spaceflight.



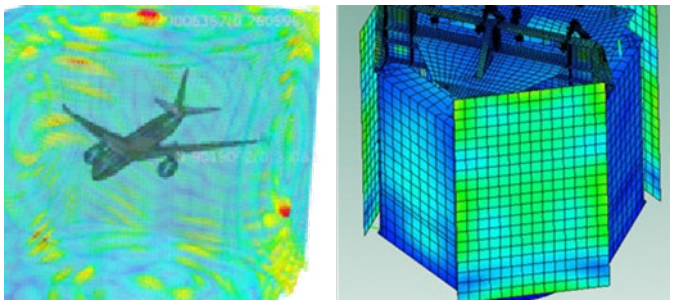
Crash, Impact & Safety analyses

Dynamics & Strength structural analysis for stress, strength, and misuse scenarios is carried out for both aerial and space vehicles to maintain structural integrity under various conditions. Aerial vehicles undergo space splashdown assessments, while space vehicles are evaluated for water floating and splashing to ensure safe reentry. Additionally, payload dynamics simulations are conducted exclusively for space vehicles to optimize payload deployment and stability.



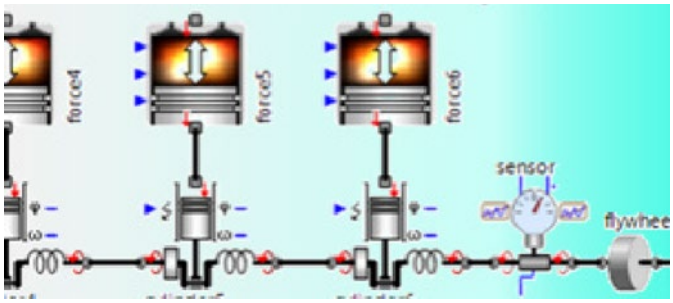
Strength & Dynamics validation

Seat and Interior for space vehicles, cockpit, cabin, and seat designs are meticulously evaluated to ensure ergonomic and functional suitability for astronauts. In contrast, for aerial vehicles, static and dynamic comfort analyses, thermal comfort assessments, and ergonomics evaluations are conducted to enhance passenger comfort and well-being. Furthermore, trim manufacturing simulations are performed exclusively for aerial vehicles to streamline interior manufacturing processes.



Vibro-Acoustic simulation

System Performance optimization of propulsion and transmission systems, hydraulics & pneumatics, vehicle dynamics, and electrification & energy management is essential for both aerial and space vehicles. These simulations ensure efficient and reliable operation across various mission profiles, contributing to the overall performance and mission success of both vehicle types.



Energy management

The Future of Vehicle Safety Engineering will be 100% Digital

Vehicle development involves considering numerous variables that form the product's design space. Exploring and assessing all possible combinations of variables is impractical and costly with conventional methods, such as Design of Experiments (DoE) and traditional CAE optimization. These methods have limitations in scope, time consumption, and cost, requiring specialized skills.

Here at Keysight, we have been developing options to equip our vehicle models with cutting-edge model order reduction functionality, powered by hybrid Artificial Intelligence to create a parametric model of the design space with fewer and more affordable simulation runs. We work towards empowering both skilled and non-skilled engineers to swiftly grasp the variables' effects and pinpoint significant combinations that yield desired results, allowing them to prioritize load cases and design parameters for in-depth examination.

Fast parametric design space exploration could then be used for:

- Virtual crash test results, optimizing vehicle safety, weight, and cost in a limited timeframe
- Low-speed RCAR insurance assessment, optimizing crash repairability and safety ratings
- Airbag validation testing, ensuring compliance with safety standards and optimizing performance under various crash scenarios

The 3x3 Most-Wanted Capabilities of Keysight's Virtual Crash & Safety Testing Approach

In the field of crash and safety simulation and virtual testing, Keysight stands out with its innovative product features and deep expertise. Here's why:

1. Single core model: With a common 3D simulation model, VPS simplifies the load case process, allowing for a broader range of assessments in the same timeframe. This concurrent engineering approach fosters product optimization and innovation, ensuring adaptability as load cases evolve.

2. Fastest crash solver: Studies confirm VPS's superior speed in handling complex, multi-core cases, yielding quicker results and enabling more simulations within tight deadlines.

3. Consistency of results: VPS boasts unmatched consistency in simulation outcomes across diverse environments, instilling confidence in the reliability of results, particularly valuable when collaborating with CAE partners or across multiple offices.

4. Real-world fluid/structure interaction: Keysight's Finite Point Method (FPM) technology revolutionizes traditional mesh-based CFD methods, offering faster, more accessible fluid mechanics assessments. It accurately simulates fluid dynamics' impact on vehicle structure, streamlining pre-processing resources and enabling engineers without deep CFD expertise to conduct robust analyses.

5. Multi-scale modeling: VPS's multi-scale modeling capability revolutionizes simulations featuring varying levels of detail, allowing simultaneous analysis on the same model. This streamlines complex analyses while maintaining accuracy, crucial for scenarios like small overlap crash tests or simulations involving composite structures.

6. Modular material model: Keysight's Modular Material Model simplifies material physics, consolidating multiple behaviors into a single model for implicit and explicit cases. This reduces manual overhead, enhances flexibility, and expedites experimentation by facilitating easy material changes.

7. Simulation workflow automation: VPS's Visual Environment offers customizable API automation and process template tools, streamlining pre-processing, solving, and post-processing tasks. This automation minimizes manual efforts, freeing specialist engineers for higher-value activities or additional experimental studies.

8. Depth of Keysight Expertise: Backed by decades of experience, Keysight's crash and safety simulation experts offer unparalleled knowledge and support, addressing a myriad of use cases and delivering reliable, accurate outcomes for high-quality, safe vehicles.

9. Visionary & courageous pioneership: Keysight has a proven track record of groundbreaking innovation, from conducting the world's first predictive digital crash test in 1985 alongside Volkswagen to leading the way with product reviews in the industrial metaverse. Our expertise in solving complex simulations at scale and pioneering research in hybrid artificial intelligence make us the go-to choice for safety engineers, enabling them to conduct over 1,000 tests swiftly and efficiently.

Conclusion

In this whitepaper, we've uncovered the pivotal role of virtual testing and simulation in creating safer, more reliable, and cost-effective vehicles. As you strive for ultimate safety and efficiency in engineering, we urge you to champion the democratization of simulation.

By making safety validation accessible to all team members, regardless of expertise, you empower everyone to contribute meaningfully. Additionally, take a holistic approach to safety engineering. Integrate design, performance engineering, testing, and manufacturing processes seamlessly to provide a cohesive and efficient lifecycle. A single source of truth ensures alignment and clarity across every stage.

We are all aware that in today's fast-paced world, speed is essential. Look for software solutions that can accommodate multiple tests within the same timeframe, enabling thorough exploration of design space without sacrificing accuracy.

Precision is paramount in simulation results, so pay meticulous attention to detail, including considerations of manufacturing effects. Lastly, prioritize knowledge and expertise because trust and reliability are built upon a foundation of deep industry knowledge and consistent delivery. Choose vendors who consistently demonstrate reliability and expertise in their results.

Engage with us! With our proven virtual prototyping approach, you gain the tools to make informed crash and safety-related decisions swiftly and collaboratively. Let's work together to drive innovation and safety in vehicle engineering.

For more information visit the **Keysight CAE website**