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REVIEW OF VIRTUAL REALITY APPLICATIONS FOR REDUCING TIME AND COST OF VEHICLE DEVELOPMENT CYCLE

Mr Jasna Glišović *
University of Kragujevac, Faculty of Mechanical Engineering, Kragujevac, Serbia
Dr Miroslav Demić
University of Kragujevac, Faculty of Mechanical Engineering, Kragujevac, Serbia
Mr Danijela Miloradović
University of Kragujevac, Faculty of Mechanical Engineering, Kragujevac, Serbia

The vehicle development process has been defined by increasing requirements for quicker and less costly development cycles, combined with reduced vehicle fuel consumption. The complete requirements for new vehicle development include the need for rapid prototyping and durability evaluation to achieve an accelerated vehicle development process. There is now a convergence of market and technical changes that directly affect this development process. A clear trend in the automotive industry is that the manufacturers outsource more development work to subcontractors. Consequently, the overall quality of the finished product will depend on how well the automotive companies and the subcontractors work together in the development processes. Lack of harmonization between the subcontractors and the automotive company – but also between different development departments at the manufacturer – causes expensive errors. Although research in virtual reality has been done for over 20 years, only a few years ago the non-academic world started to evaluate its use to solve real-world problems. Among others, the automotive industry is evaluating its potential in design, development, and manufacturing processes. In fact, the automotive industry has been among the first, but others, such as suppliers, have begun to evaluate VR, too. The resulting benefits of using Virtual Technologies (the reduction of development time, the reduction of development costs-better design through virtual pre-checks, less modifications and increasing quality) are presented in this paper.

Key words: virtual reality, vehicle, development cycle

INTRODUCTION

Automotive manufacturers are pressured to deliver complex products with increased quality in shorter development cycles. Engineering the performance of mechanical designs with traditional test-based development processes is no longer an option. The only valid alternative is evaluating functional performance attributes on a virtual prototype. Modern software enables engineers to effectively analyze and optimize real-life performance of mechanical systems, long before physical testing.

The most challenging task for engineers is to guarantee that the dynamic performance of their mechanical systems will match specifications. They need to make sure that the numerous components interact and move as planned under the influence of real-life conditions, such as gravity and frictional forces. Virtual prototyping has to deliver the right answers, with the required accuracy, and on time to positively impact the development process. The best solutions are those that can be easily re-scaled to support the various stages of the entire development process. Equally important is that these solutions assess the dynamic motion performance in light of all system requirements, including durability, noise and vibration.

The entire vehicle development process requires a combination of many separate performances, how the Figure 1 shows [06]. These activities are frequently performed in separate departments with little internal communication. Automotive

* *Faculty of Mechanical Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia; jaca@kg.ac.rs*

companies are now redesigning their internal processes to coordinate these diverse tasks and provide some logical structure for communication. In addition, a more formal design process is being implemented to ensure that separate design groups can work on different parts of the development activity in parallel and also ensure that the final combined activity produces a design that meets the performance targets initially set. The typical sessions of design review are, today, performed in virtual reality rooms, where both geometric and functional features of new products are investigated. The main scope is to supply a virtual validation of the product, reducing the needs of prototyping physical mock-ups (PMUs) building.

Starting from the conceptual stage of a new product, a conceptual Digital Mock-Up (DMU) of the product is built and it represents the reference model for all the following phases of Virtual Development Product (VDP), down to the market launch and its use. CAE (Computer Aided Engineering) engineers use DMU data to create their simulation models in order to analyze and monitor the performances of the new product.

Another important technology is Virtual Reality (VR) that today seems to be very integrated in the VDP. In fact VR is used in the fields of Styling, DMU and Physical Mock Up (PMU), Design, Ergonomics, Simulation, Digital Plant, Marketing and Sales. The VR Centre is becoming the place where the designer chooses the car style model, where the car development team executes DMU design reviews, analyses alternative solutions and deliberates product and process validation.

VR represents a user interface technology that enables the interaction of the engineer with the virtual models of the car, thanks also to the immersion feature. VR allows, in fact, intuitive analysis and simple presentation of complex three-dimensional systems. Furthermore with immersive virtual environment, ergonomist can study the “man-car-environment” interaction and evaluate the comfort of a new car.

Starting from the early stages of product development a DMU is implemented to provide all geometrical constraints for designer that have to define the style of the new car. The vehicle DMU evolves along the VDP until it is delivered to the market and it represents the reference model for product a production engineers and for decision-maker teams. The core of DMU is the creation of a database containing the CAD/CAE models of car with the related structural and functional properties. The objective of the DMU is to simulate the entire development process by the use of methods and software and to integrate the DMU with style definition process, tolerance analysis, digital manikin, virtual simulation and digital factory.

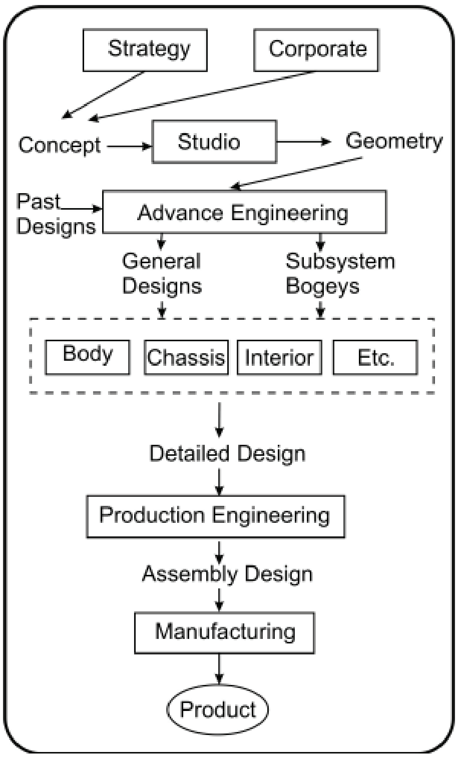

Figure 1. Vehicle Development Plan [06]

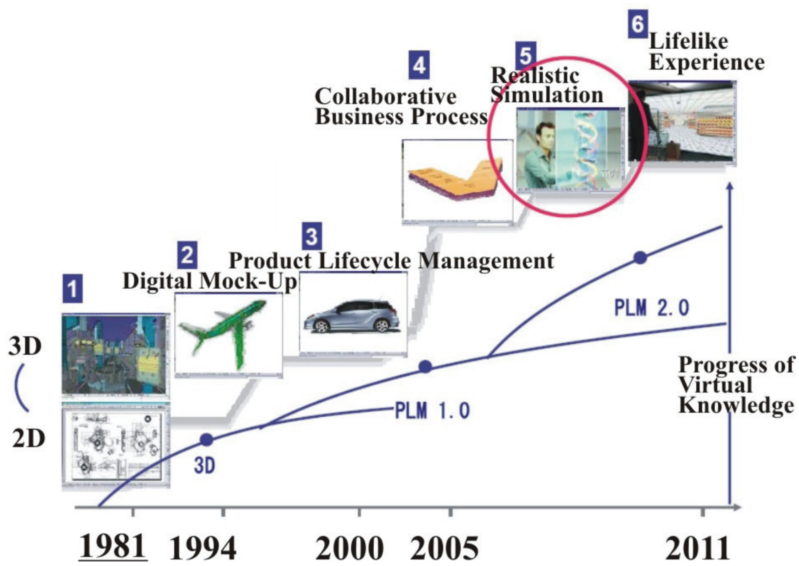

Figure 2. Progress of Virtual Knowledge

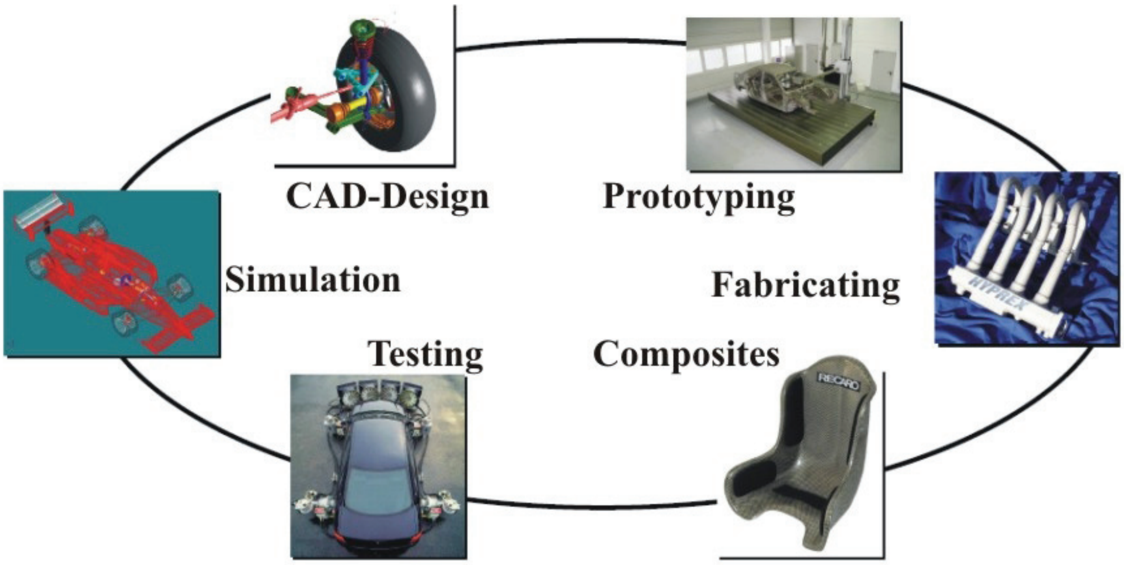

Figure 3. Digital Product Lifecycle

Previous research has shown that a virtual environment can offer a wide variety of analytical post-processing tools. For example, the Virtual Windtunnel project described by Bryson [02,01] is one of the first applications based on virtual reality techniques that clearly shows the advantages of this approach compared to traditional finite element analysis post-processing methods. Ye [13] and Yeh [14] also use a virtual environment for the visualization of finite element models which further illustrates the usefulness of this technique. The study of realistically simulated scenarios in structural and fluid mechanics involves very large, transient data sets. In the past it was far beyond the available hardware capabilities to display those data sets in real-time. However, due to advances in hardware technologies and due to the efforts of a number of researchers in the area of data reduction techniques [11], the visualization of these data sets became possible.

COMPUTER AIDED DESIGN (CAD)

Computer aided design has evolved from the simple replacement of traditional drafting equipment to a very sophisticated, highly visual design tool. The earlier CAD programs used the computer to generate lines for 2D drawings. As the software and hardware advanced, these 2D drawings could be converted into 3D objects. Modern software used for solid modeling often functions in the reverse order; the three-dimensional object is drawn and then two-dimensional, orthographic drawings are generated from that model.

Advantages of wireframe 3D modeling over exclusively 2D methods include but are not limited to:

- Flexibility, ability to change angles or animate images with quicker rendering of the changes;

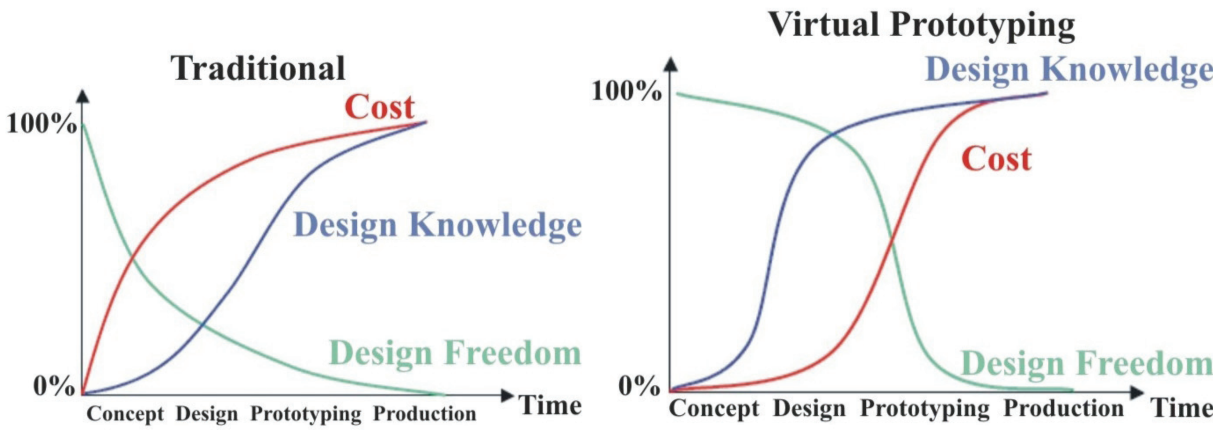

Figure 4. Comparisons between Traditional and Virtual Prototyping [15]

- Ease of rendering, automatic calculation and rendering photorealistic effects rather than mentally visualizing or estimating;
- Accurate photorealism, less chance of human error in misplacing, overdoing, or forgetting to include a visual effect.

In the product development process, prototyping is an essential step. Prototypes represent important features of a product, which are to be investigated, evaluated, and improved. They are used to prove design alternatives, to do engineering analysis, manufacturing planning, support management decisions, and to get feedback on a new product from prospective customers.

Markets are becoming more and more dynamic and quick-paced. In order to stay competitive, companies must deliver new products with higher quality and/or less cost in a shorter time. Additionally, they must provide customers with a broader variety of versions at minimum costs. Therefore, rapid prototyping and virtual prototyping (VP) are quickly becoming interesting tools for product development.

While some automotive companies have already begun to routinely use VR as a tool in styling and design reviews in the concept phase, it has not been clear that VR can be an efficient tool in assembly/disassembly simulations maintenance verifications. Assembly simulations are much more difficult in that they involve a lot of interaction and real-time simulation. However, it is revealed that the assembly process often drives the majority of the cost of a product. Up to 70% of the total life cycle costs of a product are committed by decisions made in the early stages of design.

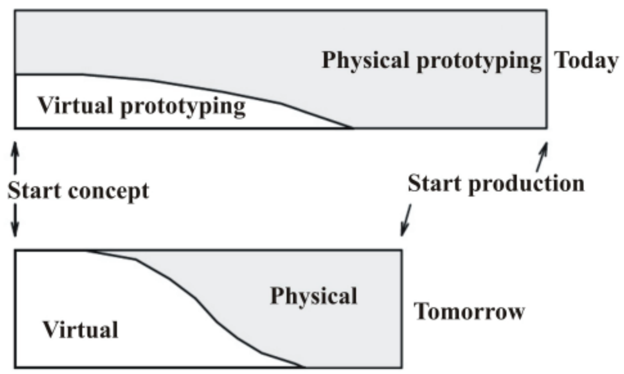

Figure 5. The goal of virtual prototyping is to reduce significantly the amount of hardware prototypes during conception, design, and evaluation of new products. The effect will be a reduction in time-to-market [15]

There seem to be two different understandings of exactly what VP is: the “computer graphics” and the “mechanical engineering” point of view. The computer graphics definition of virtual prototyping (VPCG) is the application of virtual reality for prototyping physical mock-ups (PMUs). The VR system simulates and renders all characteristics relevant to the particular context as precise and realistic as possible in an immersive environment.

In the mechanical engineering definition of virtual prototyping (VPME), the idea is to replace physical mock-ups by software prototypes. This also includes all kinds of geometrical and functional simulations, whether or not involving humans. For instance, simulations of assembly lines, FEM crash tests, etc., are VPME activities, too.

$$VP_{CG} \subset VP_{ME} \subset DMU$$

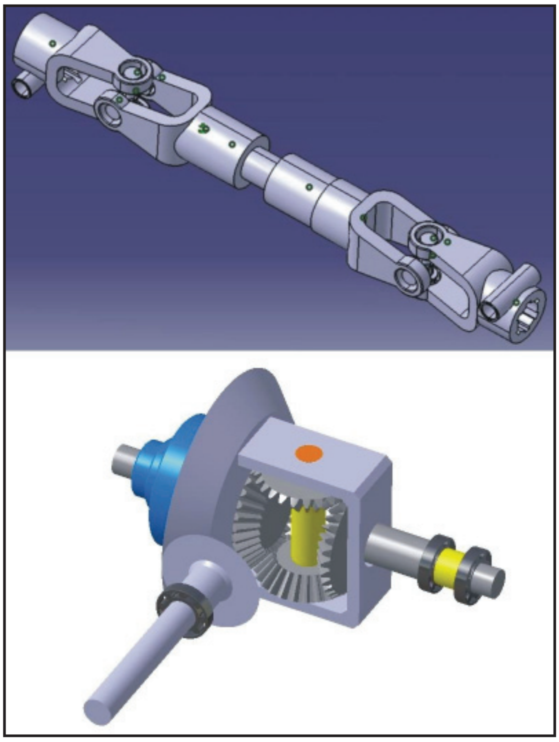

Figure 6. Assembly simulation

Digital mock-up (DMU) is a realistic computer representation of a product with the capability of performing all required functionalities from design/- engineering, manufacturing, product service, up to maintenance and product recycling. In a sense, DMU can be viewed as the medium through which stylists, designers, testers, manufacturers, marketing people, customer supporters, etc., exchange information about a new product. So, immersive virtual prototyping is but one technique for implementing the DMU strategy [15].

STRUCTURAL ANALYSIS

Modern software provides all the necessary tools for advanced designers and specialists involved in structural analysis. The processes covered include stress, frequency, thermo-mechanical, buckling and contact analysis with multiple load, restraint and mass complex configurations. Analysis can be performed on single parts as well as on hybrid models mixing solid, shell and beam elements. This allows for a wider number of mechanical behavior and sizing assessments of parts and assemblies earlier in the product development process.

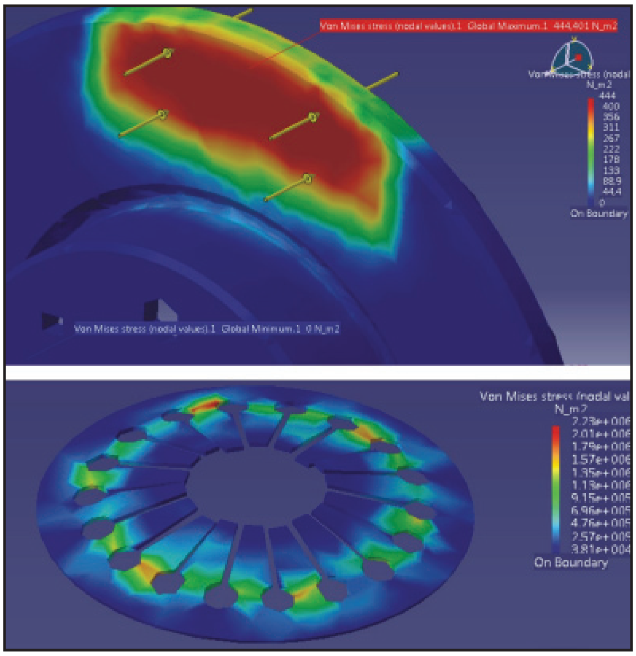

Figure 7. Stress analysis of a rotating brake disk and diaphragm clutch spring

KINEMATICS SIMULATION

A simulation is an imitation of the real thing. It refers to a broad collection of methods and applications to mimic the behavior of real systems, usually on the computer with appropriate software. Kinematics simulation is the process of modeling kinematic systems and then simulating it in the suitable environment under the appropriate constraints.

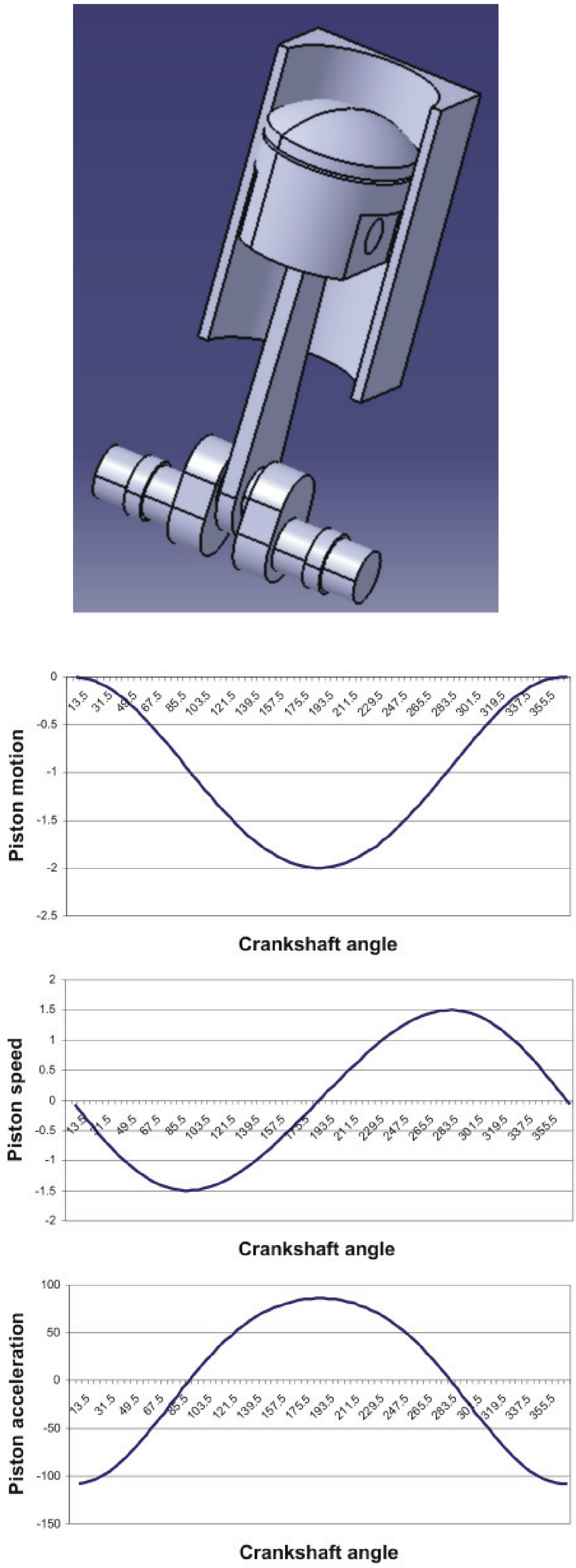

Figure 8. Simulation of single cylinder motor's kinematics [05]

Discussed below are features of the DMU Kinematics Simulator available with the software CATIA (Computer Aided Three-dimensional Interactive Application) as advertised on its website (IBM Software: CATIA).

3D mechanisms: 3D mechanisms based on different types of joints are available: Revolute, Prismatic, Cylindrical/Actuator, Planar, Rigid, Spherical, Universal, Point-Surface, Point-Curve, Roll-Curve, Slide-Curve, Screw, Gear, Rack, Cable and Constant Velocity joints. It is possible to define and verify joint limits (travel limits or joint stops) and thus guiding the design of the assembly.

Automatically generates mechanism: Constraints defined in CATIA Assembly Design product can be automatically interpreted as joints.

Simulates mechanism motion: Users can easily simulate motion using the mouse and guide possible actions thanks to a co-pilot which pops up icons under the mouse. Users can also create a wide range of kinematics laws allowing time-based simulation. The laws can be graphically visualized.

Analyzes mechanism motion dynamically: During mock-up design review, the designer can not only view simulated kinematics motion but also analyze the mechanism's consistency with the functional specifications.

Records motion analysis' results: Users can replay a motion simulation, or save it as a video file.

Generates useful information: DMU Kinematics Simulator provides the ability to define a point in a moving part and generate its trace in order to design cams. During a simulation with laws, it is possible to plot sensors according to time but this functionality also offers the possibility to plot a sensor according to another sensor. Users can run, for instance the simulation of an engine, and plot the position of an inlet valve according to the rotation of the crankshaft.

Allows automation of mechanism creation and simulation through Visual Basic macro programming: Multiple combined simulations are possible for advanced digital product synthesis when using this product in conjunction with other DMU products. For example, users can simulate and synchronize un-mounting procedures with a kinematics motion when both the DMU Kinematics Simulator and DMU Fitting Simulator products are installed.

Simulates mechanisms: The data used to create the full digital mock-up may come from any number of supported data formats, including: CATIA, STL, IGES, OBJ (from Wave front) or other multi-CAD environments. The kinematics simulation and associated kinematics analysis functions are identical whatever data format is used. If made an integral part of the design process, it can be used effectively in the testing and evaluation stages. It has the ability to replace physical prototypes and make the design process not only cheaper but also faster and more flexible [08].

ERGONOMICS IN THE AUTOMOTIVE INDUSTRY

In the last years the human factor is assuming more and more importance in the design, engineering, production and maintenance of new industrial products. In the car design a primary requirement is to assure the comfort of driver and passengers, taking into account problems related to:

- positioning of the main and secondary controls, that have to be reachable and operable through simple and natural movements;
- driver visibility that depends on general design of the interiors (i.e. seats, glass surfaces, mirrors, etc.);
- habitability and design of a driver's seat that have to minimize driver fatigue;
- accessibility (space area for driver and passengers);
- visual appeal (material, color, texture, surfaces) [09].

The car interior design process should be:

- identify the human factors that influence comfort judgment;
- identify the main design parameters;
- define and to realize a specific test to measure biological and physiological human characteristics and to get the subjective evaluations related to the different values of the project parameters;
- define final values and parameters project.

The exposed objectives are very difficult to achieve with traditional design methods (i.e. two dimensional representation, static models). The modern tendency is to use 3D human modeling software and mechanical or electronic vehicle simulator. Parametric vehicle simulators are used to reproduce the driver seat position of a new car considering the main components associated to the digital car model.

A simulation system allows to quickly identify critical aspects of the vehicle design comparing alternative solutions in a very short time and achieving a quickly convergence towards the optimum one [09].

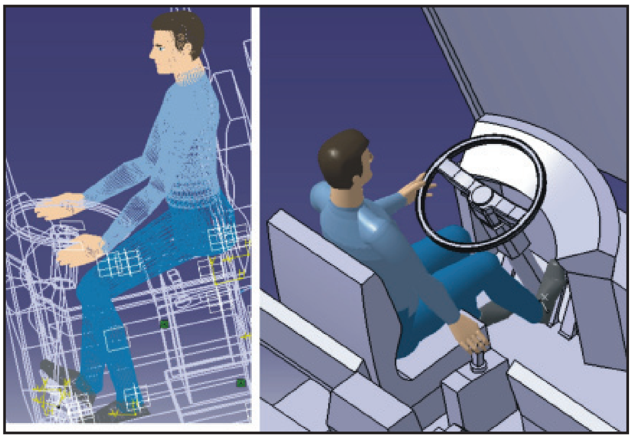

Figure 9. Human builder

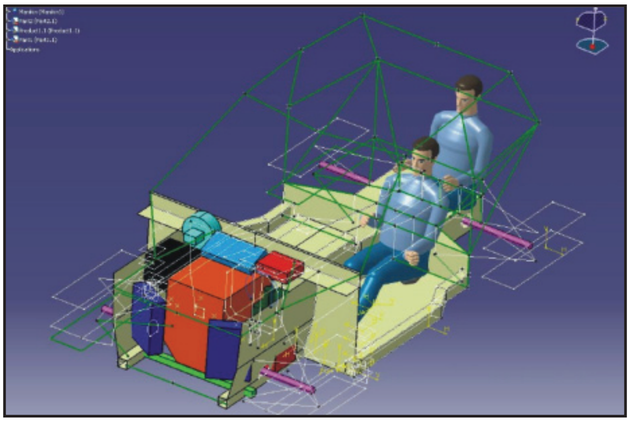

Figure 10. Driver and passenger simulation

VIRTUAL TEST ENVIRONMENT

Due to the increasing complexity of embedded systems and software in vehicles, the automotive industry faces an increasing need for testing and verification of components and subsystems under realistic conditions. At the same time, development cycles must be shortened in order for vehicle manufacturers to be competitive on the global market. Consequently, an increased amount of testing and verification must be performed in less time. However, simply increasing the volume of the testing can be prohibitively costly, implying that the testing and verification processes must be made more efficient, reducing the need for more prototypes.

While some automotive manufacturers still use clay models to prototype new cars, most of the industry's R&D centers now have the technology to create virtual environments in which to view and manipulate their designs. The use of virtual models to collaboratively review and modify designs on a desktop computer is, for the most part, a basic capability of any automotive manufacturer today, but there is one aspect of the design process-the use of interactive, 1:1 ratio immersive displays-that sets apart the cutting-edge designers from the rest of the field.

One of the main benefits of the concept is that different disciplines involved in the product development process can use the system to enhance the concurrency between them. Control systems and mechanical engineers can view ongoing tests in real time and change designs, re-simulate and influence ongoing tests in a distributed and efficient way. Through advanced visualization of simulation results and measurement data, the engineers can get a clearer view on how the system or product behaves, improving the quality of the validation process.

The concept for distributed real-time simulation and visualization will gather more information in the early stages of product development. Furthermore, it will speed up the product development process due to its real-time nature. The fact that engineers can stay at their home office and only follow the test when it is needed will enhance their efficiency.

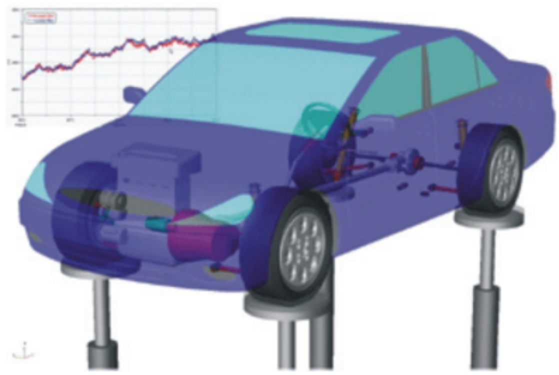

Figure 11. Virtual Suspension Test Rig

Today's automotive companies must be able to cope with distributed product development, due to the many suppliers involved in the development of vehicles. It is estimate that there are around 5000 suppliers to the automotive industry today. Since suppliers and subcontractors from all over the world frequently need to be involved in the testing and verification of the vehicles, it is necessary to develop sophisticated methods and tools for distributed validation and simulation, and to incorporate these tools and methods into the overall framework for distributed product development.

The idea with the distributed real-time simulation and visualization (DRTSV) concept is to extend the testing and verification processes, from the test tracks to the manufacturer's and subcontractors' development offices. This will result in more effective test expeditions and shorter development time. Furthermore, connecting mechanical and/or control system modules to the DRTSV concept in a black box fashion, will give the manufacturer and subcontractors a good development tool for the PD process.

Using a wireless local area network (WLAN) at the test tracks, live measurement data can be sent from the vehicles at the test track back to the development site of the manufacturer, for analysis and visualization, in real-time if desired. Having the possibility to share and view data in real-time from the test track will reduce costs and lead-times significantly for vehicle manufacturers. By integration of this framework with the system presented here, live measurement data can be used as input for hardware-in-the-loop simulation and real-time visualization, giving the opportunity to study effects not directly measurable, such as the normal forces on the tires of a moving car.

If the expert can speak to the test driver through an audio link, he can influence the ongoing test to better suit his needs. There is also a possibility for the remote expert to download new software to the vehicle directly through the wireless communication link. Working in this manner will reduce the overall test time which gives room for even more tests. All of the engineers from the home office no longer have to travel to the test expedition; they can follow the expedition from their office workplace and let local entrepreneurs perform the tests for them. This will save the automotive manufacturers and suppliers a lot of time and money.

Table 1. The different characteristics of input and output devices imply different types of VR

type	**advantages**	**disadvantages**
fish-tank VR	best resolution and least distortion; familiar and easy-to-use; fairly inexpensive.	low immersion; stereoscopic violation because of clipping; small range of user's movements.
head-coupled VR	best immersion because of large field-of-view, allsurrounding view, and almost no stereoscopic violation; fairly large range of user's movements; affordable.	either heavy or low resolution; large distortion because of wide-angle optics; not easy-to-use (intruding interface).
projection-based VR	high resolution, large field-of-view; high degree of presence, because user can see himself; easier to share; easy-to-use.	needs more graphics pipes for more walls; possible stereoscopic violation, because user's limbs always occlude virtual objects; requires a lot of space; not so easy to maintain.

By using a dynamic simulation system to simulate the behavior of the vehicle, it will be possible to access data that is hard or even impossible to measure, for instance force between tire and road and forces in joints, etc. The visualization module can be set up to present data that is interesting to many disciplines at the same time, e.g. climate, fatigue, control systems, vibration analysis, etc.

National Advanced Driving Simulator (NADS) configuration is illustrated in Fig. 12. The cab controls and displays are identical to those of production vehicles and, through computer control, vehicle dynamics is used to supply control feel feedback associated with driver control actions or vehicle motion. Vehicle dynamics computers enable drivers to experience vehicle motion in a total of nine degrees of freedom to provide accurate haptic driving cues. This motion is complemented by correlated 360-degree visual and audio cues, also under computer control. The photorealistic visual scenes provided by a high-end Evans and Sutherland image generator include moving vehicles and pedestrians to complete the driver's perception of being immersed in urban and rural traffic situations. The audio system provides appropriate sounds internal and external to the cab, including Doppler and side-to-side directional effects.

The design of NADS allows for a wide range of potential applications, including new cockpit intelligent vehicle systems (ITS) technology, control and instrument layout, vehicle control systems, driving while impaired, and problems with novice and elderly drivers. NADS virtual driving experience is intended to be a complete sensory environment that allows drivers to be immersed in realistic tasks under real-world motivations. The simulation environment permit roadway hazards and traffic conflict situations to be presented that are impractical to control on test tracks or public roads but can be experienced in the NADS without safety consequences in the event of accidents.

In the case of crash simulation, geometry together with physical properties is displayed (Fig. 13).

Figure 12. National Advanced Driving Simulator

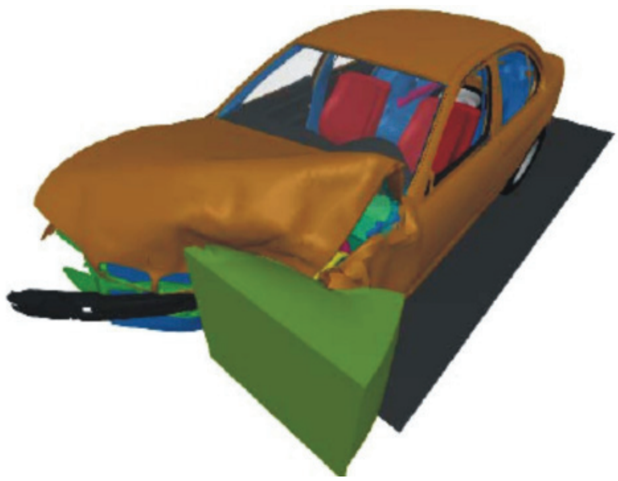

Figure 13. Car crash in the VR environment [12]

With the cost of vehicles steadily increasing as a result of heightened safety standards and growing customer demand for bells and whistles, a major overhaul of the automotive design process is taking place. Sensor technology used in interactive immersive displays is at the heart of this change, helping automakers identify, design, and assess vehicle improvements. In tandem with 3D software and other visualization technologies, motion-tracking sensors enable interactive testing and design via computer models in a fraction of the typical design time.

Interactive immersive displays are a collection of complementary technologies that, when used together, can save auto manufacturers time and money. Motion-tracking technology and advanced visualization techniques, coupled with collaborative design processes, have enabled auto manufacturers to reduce the average design time from three years to 18 months. The shorter design cycle provides manufacturers with faster time to market, enabling the designer to keep up with changing consumer requirements and offers the company a quicker return on its investment in new models and features [04].

Figure 14. Immersive visualization using seating buck

VIRTUAL PRODUCTION

The overall objective of the solutions described here is to provide a virtual-interactive environment which supports the entire life cycle of a factory. The term "virtual-interactive" denotes the capability of the environment to display and navigate through a virtual 3D-model and to allow a wide range of user interactions with this model. Towards this objective the environment must support tasks like factory design, production program planning, process optimization, and worker qualification. The applicability must not be limited to the design and planning phases of a factory, but also has to include the operation phase. Therefore the environment has to offer advanced planning, simulation and visualization capabilities under a unified user interface. Furthermore, an important requirement for such a virtual environment is its interactivity which has to be supported in different ways:

- The user must be able to interact intuitively with the virtual factory depicted in the virtual environment. He has to be able to obtain additional information by interacting with the visualized components, e.g., by selecting a station and requesting a detailed use statistics.
- The user shall be able to interactively influence the simulation run from the virtual environment by changing routings, processing times, worker allocations, etc. This provides the capability for the user to experiment with the model in an immersive environment as if he is standing in a real factory.
- The user must be able to interactively modify the simulation model. This case is partially similar to the previous alternative with the difference that the users actions indeed change the simulation model of the simulator permanently.

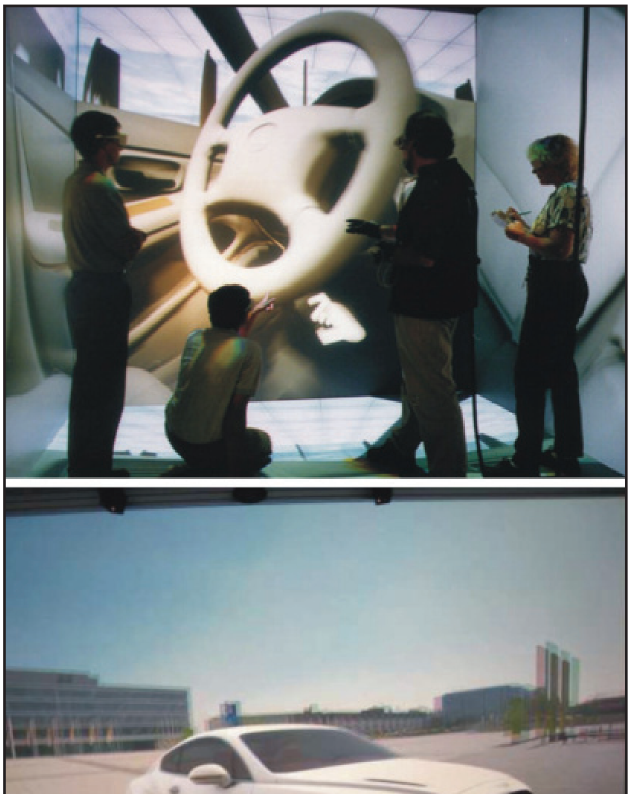

Figure 15. Interactive, 1:1 immersive displays [04]

- The user can be inserted into the simulation, e.g., take over tasks of workers which are normally part of the simulation. This can be done for training purposes, e.g., to show workers which effect certain actions will have [10,07].

“Digital human modeling is becoming increasingly important to today’s manufacturers,” says Delmia CEO Phillippe Charlès. “Determining the performance of people in the context of a workplace or a product before it exists ensures conformance to health and safety standards, accelerates time-to-market, increases productivity, and reduces design timeframe and associated costs”.

VR solutions enable worker activities to be created, simulated, and analyzed through a wide range of advanced ergonomics analysis tools that evaluate all elements of human interaction with a workcell. Using the V5 DPM planning and simulation infrastructure, digital manikins (workers representing populations around the world) perform all movements and activities associated with working within a workcell, such as walking, picking up and operating tools, tracking an assembly line, and performing installation/assembly tasks.

With the objective of training assembly workers in virtual environment different levels of training depending on the interactivity, guidance and realism required, can be distinguished.

1) Assembly Visualization
2) Assembly Procedure Training

Integrated Virtual Assembler Training.

CONCLUSIONS

The needs of reducing development time and costs and improving the car design have pushed the automotive companies to innovate theirs methods and to adopt new technologies. In this context VR is taking an increasing place because it is a technology that improves the interaction between users and virtual models, largely used in the VDP. Through a novel combination of software tools for distributed collaborative engineering, real-time simulation, visualization, and black box simulation, a system is realized that makes it possible for vehicle manufacturers and their subcontractors to work more concurrently and efficiently with testing and validation.

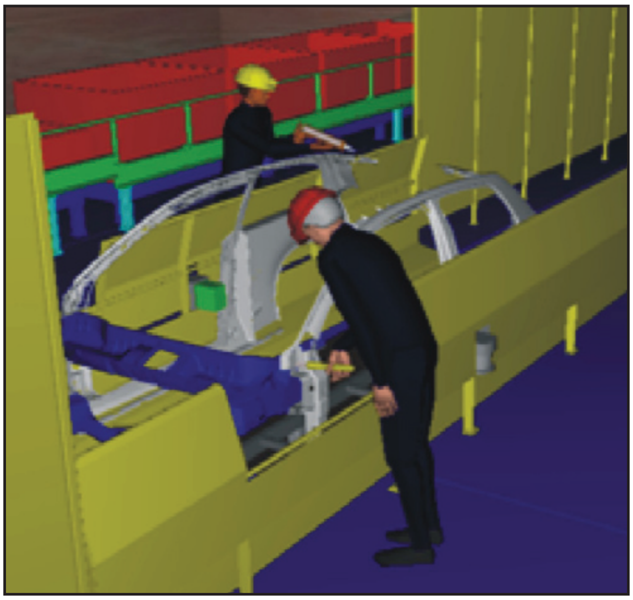

Figure 16. Ergonomic optimization of a body welding work cell [03]

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