Meet CASIMIR, the Human-Body Model

Wölfel uses Abaqus FEA and adds anatomical detail to improve design of vehicle seats

The human body is an elegantly complex structure. An adult has 206 bones, 639 skeletal muscles, countless tendons and joints, and more than 50 trillion cells. Humans are capable of running a mile in less than four minutes, jumping four vertical feet from a standing position, and bench pressing 1,000 pounds.

Even if a design team could put together a fully-detailed set of specifications for such an amazing, living machine, the human body would be impossible to build from scratch. So creating a realistic 3D computer model of it is extremely challenging. However, in the pursuit of more comfortable car seats, that is just what engineers on the Seating Comfort and Biomechanics team at Wölfel in Höchberg, Germany, are doing. Their solution, a 3D human-body model called CASIMIR (Calculated Sitting Man in Research), uses finite-element-analysis (FEA) to assess seat designs (Figure 1).

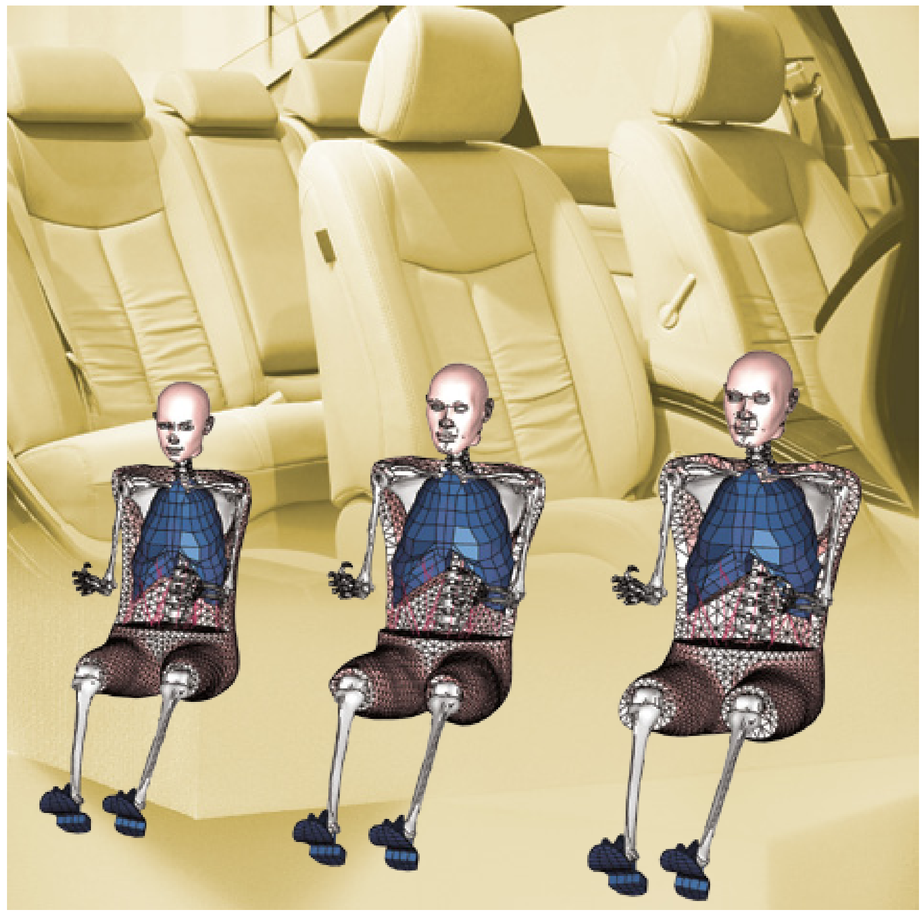

Figure 1. The CASIMIR family of human-body models includes several versions determined by the height and weight percentile that they represent: f05 corresponds to a small female; m50 a man in the 50th percentile; and m95 a large man. Adaptations can be made to account for physical variations of other nationalities and races, and an individualization algorithm further customizes the model.

Why car seat comfort is important

Seating comfort is an elusive yet increasingly important and competitive feature in vehicle seat design. Complex in nature, it is dependent on a wide array of factors: sitting position when driving, seat materials, the structure and shape of the seat, vibration from the vehicle, and the length of time spent driving, to name a few. While car seats used to be taken for granted, the simple act of a customer getting behind the wheel at a dealer can be a make-or-break moment in a potential car sale.

For those who spend a lot of time driving—such as traveling salesmen, bus and taxi drivers, airline pilots, and construction workers—issues of comfort can also become issues of health and safety. A recent survey of U.S. and Swedish drivers, for example, found 50 percent reporting low-back pain. In the EU, heavy-equipment operator safety is now regulated by the 2002/44/EC standards, which quantify daily exposure limits to vibration. At stake are issues as serious as neurological symptoms (tingling and numbness), circulatory disorders (“white finger”), and musculoskeletal problems (wrist tendinitis and back surgery).

To automotive designers, the basics of seat design—such as shape, adjustability, and the right balance of firm and forgiving foam—are important when considering comfort and health. So are the hand-arm and whole-body vibration that vehicle occupants are subject to. Other important questions include: How can seat comfort be determined so that an objective and comparative assessment is possible? And how can comfort be predicted early in the design stage before manufacturing expensive seat prototypes?

The evolution of a car-seat model

The CASIMIR human-body model has been the answer to such questions for Wölfel since 2003, as a stand-in for living human subjects in virtual analyses and optimization of vehicle seats. “CASIMIR’s advanced finite-element-analysis capabilities have proved invaluable in helping us to assess seating comfort and examine the potential health effects of a wide variety of vibrations and loads on drivers and passengers,” says Alexander Siefert, assistant manager for Seating Comfort and Biomechanics at Wölfel.

Born in the mid-1990s, CASIMIR was the brainchild of the Darmstadt University of Technology and the Federal Institute of Occupational Health and Safety (FIOSH) in Germany and was originally used to compute forces on the spine. But its value to vehicle seat designers was soon recognized, and at the Society of Automotive Engineers' (SAE) annual Digital Human Modeling Conference—where CASIMIR has been a longtime virtual attendee—ideas for its finite-element-analysis evolution have been an ongoing topic of presentations for years.

The earliest CASIMIR models were fairly abstract versions, using lumped masses connected together to represent the body. Subsequent models increased in complexity until, in the current model, volumetric parts representing the tissue of the body can now interact in three dimensions with each other as well as with the seat itself. The model's posture can now even mimic that of its human counterpart, varying from erect to normal to slouching, a feature important for evaluating low-back pain.

The elements of a seating comfort analysis

Simulating the interactions of a human-body model with a seat model is a complex process involving: material selection for nonlinear and frequency-dependent representations of seat foam, padding, trim, and human tissue; analysis of contact in the interaction zones between the metallic seat frame and foam, and between seat upholstery and the human body; and accounting for large deformations in the seat foam and human tissue. To handle such complexity, the Wölfel seating comfort team chose Abaqus unified FEA from SIMULIA, the Dassault Systèmes brand for realistic simulation. "We investigated other FEA solvers," says Siefert, "but only the capabilities of Abaqus satisfied all of our requirements."

For evaluating seating comfort, a prerequisite is to first build a model of the seat. Over time, the Wölfel team has done that, developing an extremely accurate representation that defines key properties: the material parameters of upholstery materials; and the static and dynamic stiffness and damping values of structural joints (e.g., for the recliner and seat rail).

Once the seat model is defined, a typical seating comfort analysis involves two separate studies. The first, the seating-process analysis, is static and looks at the way the body contacts the seat under gravity. With the most important aspect of this analysis being the seat pressure distribution, this calculation helps designers evaluate the fit of body parts with seat cushions, the ergonomic position of the body, and the distance between the seat frame and the skin.

The second study, a dynamic simulation, computes how the human body in combination with the seat moves up, down, and sideways when the vehicle is in motion. This simulation looks at the way in which the seat translates the motion of the car into the movement of the body, and what the subsequent loads are on the body, especially the spine. The seat-transfer function, an important component, illustrates how the seat magnifies the vibrations that pass from the road and engine through the chassis to the seat and eventually the person. A large amplification is bad. A small amplification is good (Figure 2).

For both types of analyses, the team has utilized Abaqus Standard, based on an implicit solver scheme: the static analysis uses a nonlinear solver algorithm and the dynamic analysis a steady-state solver in the frequency domain. Four CPUs with Linux 64-bit Red-hat operating systems and approximately 64GB total RAM, powered the calculations.

In the end, the seating comfort analyses using a homogeneous version of the CASIMIR model (in which different tissues like fat and muscles are not differentiated) have shown good correlation with real measurements. Using this tool, the Wölfel team has successfully employed simulation for years to design seats (Figure 3). Virtual prototyping has helped them zero in on features, compare different designs, and rapidly optimize for both static and dynamic comfort. As testimony, many automakers—including BMW, Mercedes-Benz, and Ford—have seats on the road that have benefited from CASIMIR's input.

In addition, simulation has minimized the need for expensive physical prototypes. "Designing and building a single hardware seat prototype can cost 10,000 to 20,000 euros and take from several days to weeks, while model setups take less than a day," says Siefert. "And car-seat development always involves a lot more than only one design iteration. So the savings from using simulation can be significant."

Furthermore, according to Siefert, by using a human-body model for car-seat analyses, resonance/vibration problems can be detected early on, expensive design changes late in the cycle can be avoided, comfort simulations can be standardized, and outside-the-box designs can be considered.

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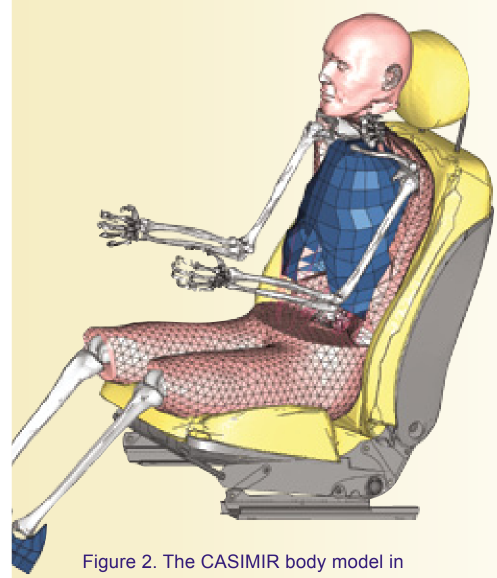
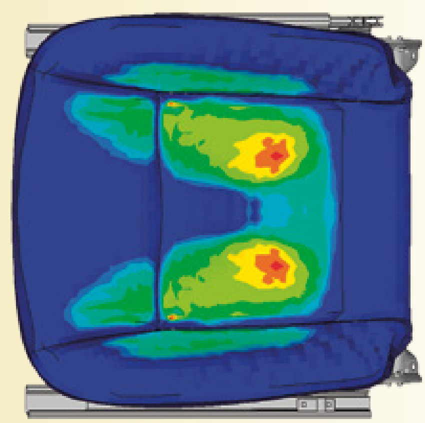


Figure 2. The CASIMIR body model in combination with a seat model includes contact definition between the structural frame of the seat and the upholstery, as well as between the upholstery and the human-body model.



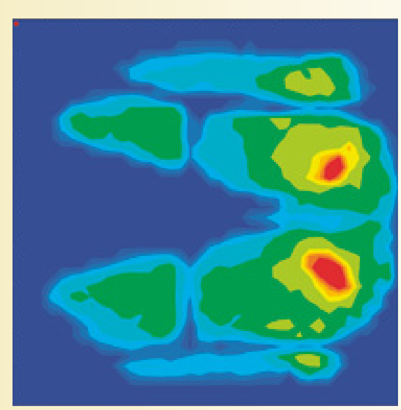


Figure 3. A typical seat-pressure distribution on a standard seat (from a static seating comfort analysis) shows a good correlation between CASIMIR (top) and measurements from a test driver (bottom).

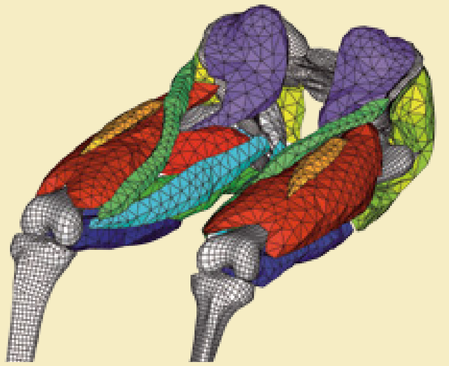


Figure 4. MRI imagery is assembled into 3D geometries, meshed, and then imported into CASIMIR's enhanced thigh and buttocks continuum model. In the model, muscles are represented in different colors.

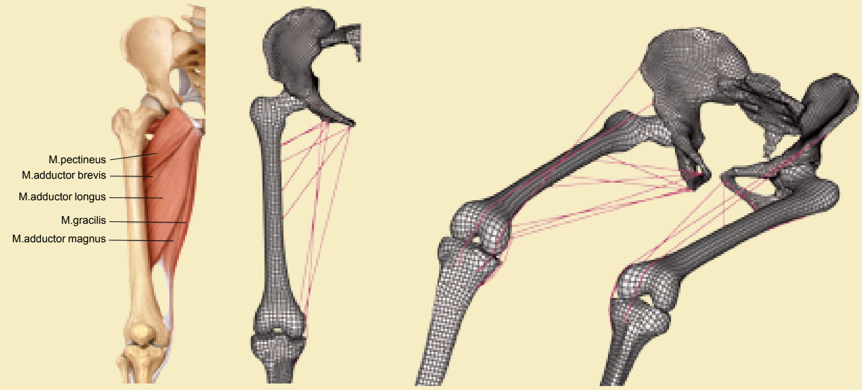


Figure 5a (left). Anatomical presentation of the thigh musculature and the realization in CASIMIR's discrete muscular model. Muscles that are connected to the skeleton on a line, rather than a single point (e.g., M.adductor magnus), are implemented by using more than one string in the model. Figure 5b (right). Discrete muscle model of the thigh and buttocks for CASIMIR includes 52 strings.

"CASIMIR combined with the power of Abaqus FEA gives us the ability—and the freedom—to cost-effectively pursue innovative concepts in car-seat designs," says Siefert.

More anatomical data creates better realistic models and simulations

While CASIMIR has already provided automakers and their customers with better designs and improved comfort, the Wölfel team believed that an enhanced CASIMIR could provide even more. When looking to improve the model's capabilities, the rule-of-thumb was this: where the functionality and response of the human body is concerned, the more realistic the model's anatomy is, the more accurate the results of the simulation. "By adding additional anatomical data to CASIMIR, we are able to increase the accuracy of our simulations," says Siefert.

As a first step in enhancing CASIMIR, the Wölfel team developed a continuum model of the thigh and buttocks area, which represented the fat, muscles, and skin separately. To make the model more realistic, they took data from the U.S. National Library of Medicine's Visible Human Project (photographs of 600 cross-sections at 1 mm thick intervals, supplemented by CT and MRI images), assembled the 2D cross-sections using SCAN-IP, and then imported the digitized anatomy into the model. The result was more lifelike 3D muscle volume detail. They then meshed the model with the HyperMesh pre-processor, using 43K linear tetrahedron elements, with a typical size of about 20 mm and only 47K DOFs for the buttock tissue, to shorten computation time (Figure 4).

The team further enhanced CASIMIR's thigh/buttocks area, developing a discrete muscle model that more accurately represented the complex musculoskeletal behavior of the body's hip and thigh. Starting with a standard anatomy atlas as reference, they used spring and damper elements (similar to those used in automotive fatigue analyses) to simulate the active muscle behavior. To define the muscle's line of action, they used strings (Figure 5). And around the joints, where the muscle action is most complex, they defined a muscle path (the shortest distance over the joint) and attached it by connector elements to the skeleton.

Applying both enhanced thigh/buttock models within the standard simulations, the team found that, in the dynamic analysis, muscle activity influenced seating comfort. More specifically, they determined that as the muscles of the thigh/buttock's area were flexed, there was a reduced rotation of the pelvis and a higher compression on the intervertebral discs of the lumbar spine. In addition, they established that these internal forces, which can cause low-back pain, were accentuated at the human body's natural resonance of 5 Hz, a frequency that is excited by normally occurring driving conditions. Overall, the results gave the team a better window into how the body experiences internal forces while vibrating and moving on the seat.

The analyses also gave the team guidelines for how to improve seat designs. When a driver, for example, pushes on the gas and brake pedals, the muscles of the leg flex and stiffen, affecting the comfort of the seat. Passengers, on the other hand, are more passive and do not activate their leg muscles. Making this distinction, the team can now use the original homogeneous CASIMIR model for passenger simulations and the enhanced CASIMIR for driver simulations.

The enhanced driver simulation, in turn, will provide more accurate guidelines for improving driver-seat designs, such as adding length to the seat to better support the thighs.

To advance their car-seat simulation capability even further, Wölfel engineers continue to refine CASIMIR. The team is already modifying it to combine the volumetric and discrete muscle models and include their interaction. They are also planning enhancements for the shoulder-hand-arm system, as these parts of the body are integral to comfort and health as well.

In related applications, Wölfel is even planning to return CASIMIR to its biomedical roots and use it for the development of implants to stabilize the lumbar spine. There is also talk of turning their increasing tissue- and skeletal-modeling knowledge to a variety of other biomechanical simulations, such as implant designs for the knees and hips, as well as design improvements for wheelchairs, office seats, and mattresses (to prevent bedsores).

With CASIMIR in the driver's seat and still evolving, Wölfel continues to point automotive engineers toward new and improved seat designs. When innovations in seat designs are brought to market, drivers of all kinds—commuters, commercial, and industrial—can look forward to a more comfortable ride, less vibration and loads, and the promise of long drives with less driver fatigue and low back pain.

For More Information
www.woelfel.de