Preparing of a Simulation System for an Examination of Non-Conventional Seating Positions in the Case of a Self-Driving Car

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Abstract: In recent years, society has turned it is gaze ever further away from vehicles with conventional drive systems such as the internal combustion engine towards vehicles with electric motors. In the course of these ideas, the concept of autonomous driving is increasingly coming to the forefront and crystallizing as a wish. The article introduces the field of vehicle safety in general and lists possible injury criteria. After that, the current concepts of fully autonomous vehicles will be presented. The aim of the research is to investigate the effect of different rotated seat positions on the injuries of passengers in the event of an accident using a simulation model. The article presents the applied simulation procedure, the simulation results and its validation. The article pointed out that the kinematics of the driver's movement during an accident changes radically as a result of the rotated seat positions, which significantly increases the chance of fatal injuries.

Keywords: Crash test; Occupant safety; Finite element method; Electric vehicles; Autonomous driving

1 Introduction

In recent years, society has turned it is gaze ever further away from vehicles with conventional drive systems such as the internal combustion engine towards new concepts with innovative systems. This includes the development of electric vehicles with electric motors or concept ideas for means of transport with a hydrogen drive. This change is caused by the change in environmental awareness and human curiosity. In the course of these ideas, the concept of autonomous driving is increasingly coming to the forefront and crystallizing as a wish for the future. In addition to a need for protection for the occupants, there is an increase of interest in comfort and economy.

Nowadays, the proportion of accidents caused by incorrect behavior by the vehicle driver still puts any other factors, such as weather and road conditions, in the background as causes for an accident. The introduction of the ESP obligation in 2014 in the European Union for the registration of new vehicles shows, for example, that autonomous systems have a positive influence on road safety. The number of accidents will decrease as the development of autonomous driving continues. The goal should be to achieve zero traffic accidents. Since almost all accidents can now be avoided by the combined application of existing vehicle technology and safe road user behavior, this goal does not seem impossible. [1]

Autonomous driving is divided into five levels. This structuring has established itself worldwide in the automotive industry. The stages of autonomous driving are included in a development process and can also be viewed as a timeline. It is important to note that, while the automatic system only performs its tasks according to predetermined rules, the autonomous systems can learn from those around them and can independently decide how to act. There is no autonomous at level 0. The occupant is the driver of the vehicle and is independently responsible for steering, accelerating and braking. Except for warning systems, no vehicle systems actively intervene in the control. In the next stage, systems are already in place that control either the longitudinal or lateral guidance of the vehicle. Once the driver has selected a particular guide, the system is responsible for the other function. Level 2 is partial autonomous. The driver is able to completely hand over the longitudinal and lateral guidance to the system. The driver is still responsible for monitoring the vehicle and the traffic because the occupant must be able to regain control of the vehicle at any time. With level 3, semi-autonomous driving, it is not necessary for the driver to have to constantly monitor the system. Only in the event of a borderline case does it have to be guaranteed that the vehicle will be taken over after a reasonable handover time. Level 3 is also the current series status of the latest vehicles. At the moment, the development is on the threshold of highly autonomous driving, level 4. The driver is able to completely transfer a specific driving task to the system. These are specific tasks for which the parameters can be narrowed down, which is the main difference to the last level 5, autonomous driving. In the future, there will be no more limits to driverless driving.

As a result of this development, the driver in an autonomous vehicle only finds himself as a passenger. The typical upright and straight sitting position is no longer absolutely necessary and desirable for reasons of comfort. The development of driverless vehicles by the automotive industry is changing driving behavior. The driver becomes a passenger and can perform activities and no longer need to pay attention to controlling the vehicle. Thanks to the freedom gained, it is no longer necessary for the driver to remain in an upright sitting position facing straight ahead. An important research direction can be the influence of a rotating seat in the first row of seats in a car on future restraint system is shown.

2 Vehicle Occupant Safety

Vehicle occupant safety includes active and passive safety. A distinction is made here, which is structured as follows: measures to limit the consequences of an accident (active safety) and systems to reduce the consequences of an accident (passive safety). The active safety systems intervene to support the driving operation. The detection of the driving condition is recorded and evaluated with the help of various sensors. In the event of deviations from defined limit values, the driving condition is intervened.

For example, the electronic stability program (ESP), which has been mandatory for all new vehicle registrations since 2014, detects acute dangerous situations, such as rotations around the vertical vehicle center axis and engages through a specially calculated braking of individual wheels. Another system is the anti-lock braking system (ABS). This may prevent the vehicle from swerving when braking. In order to protect the occupants of a vehicle from serious or even fatal injuries in the event of an accident, the passive safety systems must come into effect. The vital parts of the body such as the head and chest are particularly safe. The consideration of these areas takes place in-depth. The combination of active and passive safety, as well as the consideration of the entire course of the accident from the origin of the accident to the rescue service, lead to integral safety. The aim is to optimize the protection potential of all road users.

The governments of different countries have taken several measures to improve road safety for vehicles. This is based on the UN / ECE regulations that were established in 1958 by the United Nations Economic Commission for Europe (UNECE). Nowadays, the regulations for North America are laid down in the Federal Motor Vehicle Safety Standards, or FMVSS for short, whereas in Europe the ECE regulations (Economic Commission for Europe) form the basis for road safety regulations. An essential difference between these regulations are the unbelted load cases in the United States. Other countries have their own laws. [2]

The statutory regulations stipulate minimum requirements for individual components and assemblies that must be met. If the requirements of the law are not met, there is no type approval for the respective vehicle. Since the statutory provisions only reflect a fraction of the total number of accidents, additional consumer protection load cases have been developed by independent private institutes. The most important organizations for the continuous development of consumer protection in motor vehicles include the NCAP institutes (New Car Assessment Program) and the IIHS (Insurance Institute for Highway Safety). These crash tests are conducted by NCAP institutes such as C-NCAP (China), Euro-NCAP (Europe), US-NCAP (United States) and the IIHS (Insurance Institute for Highway Safety (North America). The NCAP programs are adapted to the respective regions. One example is the different requirements in the event of a side crash in the USA, because the proportion of large vehicles such as SUVs

(Smart Utility Vehicles) is significantly larger there. Another difference between the individual NCAP institutes is the different evaluation method. The aim of the legislation and consumer protection regulations is to make an objective safety assessment possible in the automotive industry. The automobile manufacturers are not able to do this obliged to pass the consumer protection load cases positively, but the results are freely available he customer the opportunity to compare vehicles from different manufacturers with regard to their safety.

A crash is a very sharp and abrupt deceleration of the vehicle. With the law of conservation of momentum, the occupant tries to move on with the speed vector after an impact. The use of different restraint systems includes the task of reducing the relative speed that prevails between the occupant and the vehicle so that the impact of the occupant on the vehicle interior structures does not have fatal consequences and a reduction in the severity of injury is achieved. A reduction in the impact speed is achieved by holding the passengers in the seat. The seat ramps are coupled to the seat to prevent the submarining effect, which reduces the pelvis from sliding forward and thus makes it more difficult for the occupant to slip under the lap belt. The restraint effects of the airbag and the seat belt are not impaired. The headrests belonging to the seat prevent or reduce the overstretching of the cervical spine and the associated serious injuries in extreme cases and mainly in the event of a rear impact. The basis for occupant protection systems is generally the body of each vehicle, which is not explicitly assigned to the occupant protection system. The body has two crucial tasks that are initially mutually exclusive. On the one hand, the external structure of the vehicle is responsible for providing a sufficiently high level of rigidity for the passenger cell so that the survival space for passengers is guaranteed. On the other hand, it is necessary that the deformation elements of the body are sufficiently deformable in order to convert sufficient kinetic energy into deformation energy.

2.1 Injury Criteria

Classification of injuries requires a comprehensive evaluation principle. The AIS (Abbreviated Injury Scale) is most often used in accidents, is an anatomically based global severity scoring system. This scale basically expresses how life-threatening the given injury is. Its very first version was published in 1969, but since then there have been many updates, the most recent in 2015. Each injury is characterized by three parameters on the scale, these are type, location and severity. The scale classifies the types of injuries into six groups, these are whole area, vessels, nerves, organs, skeletal and loss of consciousness. The scale classifies the location of injuries into a total of nine groups, these are head, face, neck, thorax, abdomen, spine, upper extremity, lower extremity and unspecified. The scale classifies the severity of injuries into a total of seven groups, these are minor, moderate, serious, severe, critical, fatal and not further specified. [3]

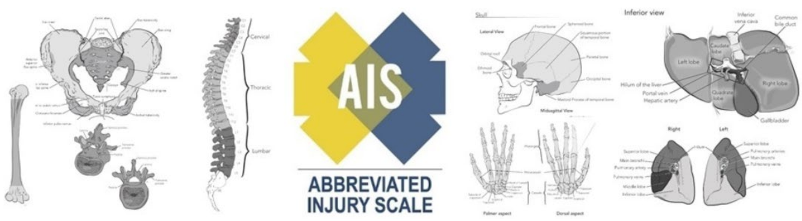

Figure 1
Abbreviated Injury Scale [3]

During crash test analysis the most important measured values in the head area include the translational accelerations, which are measured in the center of gravity of the head. From these, the head acceleration value a3ms head and the HIC (Head Injury Criterion) are calculated. The head acceleration value a3ms, which is specified over a period of t=3 ms, represents the greatest acceleration of the head. For legal requirements, such as according to FMVSS208 (United States), a value below 80g must be met. In order to achieve a maximum number of points at the Euro-NCAP, this must not exceed the value of 72 g. Acceleration values in the x, y, and z directions are displayed as a_x, a_y, and a_z. The limit value for head injuries due to acceleration is defined for a time interval of 15 ms, which represents a hard impact, and a time interval of 36 ms, which describes a softer head impact. For example, in FMVSS208 (United States) load cases for frontal impact, a HIC of 700 is given, while the values required to reach the maximum Euro-NCAP frontal impact score must be below 500.

Another important area of injury is the neck. The Nij (Normalized Neck Injury Criterion) is used to assess cervical vertebrae injuries, taking into account occupant size. The causes of injuries to the cervical spine lie in the acting axial tensile and compressive forces and the bending moments around the transverse axis at the transition from head to neck, which is why these values are used to calculate the injury criterion. To determine the loads acting on the chest, the chest compression is determined in addition to the chest acceleration a3ms. In general, according to FMVSS208 (United States), a relative compression path between the sternum and the spine of 50.8 mm must not be exceeded in the case of contact between surfaces of any kind. This would cause serious internal and external injuries in the area of the upper thorax. In the event of contact with the airbag system, the upper limit is 76.2 mm based on the assumption that force is applied over a larger area. When using belt systems, the lower limit value must be observed.

Knee injuries are increasingly occurring due to very large pelvic displacement values. This is the case in particular with unbelted occupants. The cause can also be found in connection with the so-called submarining effect, in which the vehicle occupant can slip under the seat belt. In addition, foot space intrusions restrict foot movement, which is why pressure and bending stresses arise in the lower leg, which are associated with a high risk of fractures and ligament ruptures. Due to the different forces acting between the thigh and tibia, a displacement in the knee can occur. Therefore, this displacement, also known as the kneeslider effect, between the upper and lower leg was defined as a protection criterion for the knee joint. Since bending moments occur in addition to compression forces when impacting the instrument panel, the tibia index is used to assess the risk of injury to the tibia.

3 Current Concepts for Fully Autonomous Vehicles

Today the automotive industry is making great strides towards driverless driving. In this chapter, four concepts from the automotive industry are shown in order to show the variety of seating positions of the visions. The first model to be presented is the F015 concept study from Daimler AG. The futuristic design combines many different new ideas. On the one hand, the vehicle structure is fundamentally different compared to today's vehicle models. The lack of a B-pillar means that the interior of the vehicle can be given completely new functions. In *Figure 2* it can be seen that this vehicle concept is equipped with four individual swiveling seats. The angle of rotation that can be achieved with these vehicle seats is not clearly visible, but this Figure shows a face-to-face constellation of the four seats.

Figure 2
Vehicle concept (left) and interior concept (right) of the F015 from Daimler AG [4]

With its concept study 360c, the Swedish car manufacturer Volvo offers another idea for driverless driving (see *Figure 3*). However, this concept offers several variants compared to the concept studies from Daimler AG. In general, the face-to-face sitting position is given for the interaction between occupants. However, there is also the variant in which the seat back is set almost horizontally and the occupant is in a lying position. The concept shows that sleeping shouldn't be a problem in general, as it will be a fully autonomous vehicle.

Figure 3

Vehicle concept (left) and interior concept (right) of the 360c from Volvo AG [5]

Most of the concept studies presented are image advertising. However, these concepts offer insights into possible future design ideas and ideas of self-driving vehicles. None of the concept ideas mentioned go into detail on adjustments to restraint systems to protect passengers. The research phase is on to change the impact boundary conditions and the behavior of current restraint systems and,consequently, sensible solutions. In addition, protection systems and new concepts for protection systems can only be designed once the vehicle structures have been coordinated.

There are some taxis on level 4 without driver in use one of them is the Cruise AV. The Cruise AV is a Chevy Bolt-based autonomous vehicle; the first generation (G1) were modified by Cruise in San Francisco while the subsequent second and third generations (G2, G3) are manufactured at the Orion Township assembly plant in Michigan. The Cruise AVs feature drive control algorithms and artificial intelligence created by Cruise. The Cruise AV uses Lidar, radar, and camera sensors. In September 2021, Honda started testing program toward launch of Level 4 mobility service Business in Japan, using the G3 Cruise AV.

Figure 4

Cruise AV self-driving taxi [6]

Another important company developing driverless taxis is a Waymo. Waymo is an American autonomous driving technology development company. It is a subsidiary of Alphabet Inc, the parent company of Google. Waymo operates a commercial self-driving taxi service. In October 2020, the company expanded the service to the public, and it was the only self-driving commercial service that operates without safety backup drivers in the vehicle at that time.

Figure 5
Waymo self-driving taxi [7]

4 Description of the Simulation System

4.1 The Algorithm of the Simulation System

Due to the rapid technical development in recent years, it has become possible to solve static and dynamic problems mechanically with the help of computer simulations. This change from physical, tangible product creation to virtual product creation is becoming more and more common in industry. Computer Aided Engineering (CAE) is making a significant contribution to this trend. It offers the possibility of computer-aided modeling (CAD) through computer-aided execution and evaluation (CAT) to computer-aided manufacturing (CAM). In order for a component to be simulated and calculated, it is necessary to transfer the geometry defined in the design file to an FEM (Finite Element Method) model.

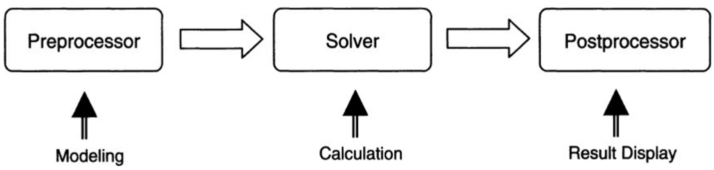

Figure 6
Simulation steps [8]

In order to carry out this activity and to model the necessary adjustments, the ANSA preprocessor from BETA CAE Systems used in this work. After the boundary conditions and the model have been transferred, the solver is able to determine and solve the differential equations and save them in an output file for each time step. The LS-Dyna solver from Livermore Software Technology Corporation is used for the simulations set up to calculate the FE model. By using the postprocessor Animator 4 from GNS mbH and in combination with ANSA META, the results in this work are evaluated and made available graphically. ANSA META is a postprocessor developed explicitly for ANSA. Analysis results include deformations and movements over time, as well as stresses and natural frequencies can be displayed.

The finite element method describes a mathematical-numerical method for solving physical problems. Areas of application include structural mechanics, heat transfer, and fluid mechanics. In order to be able to determine the stresses and deformations of the systems to be examined, the structure must be divided into a large number of finite elements, the so-called finite elements. Depending on the modeling, suitable elements are used. These can take on one, two or three dimensional forms. Solid elements (tetrahedron or hexahedron elements) are required for a three-dimensional continuum. [8]

The use of special elements such as the shell elements for the representation of "thin-walled" components, for example sheet metal structures, can be useful and are assigned to the two-dimensional forms. In addition, there are also bar elements or spring and damper elements. The combination of different element types is possible and necessary in the field of multi-body simulation. The vertices that form the finite element are called nodes. The node movement in three-dimensional space and the associated deformation of the bodies are calculated for each individual node. Partial differential equations of the 2nd order are set up and solved. Acceleration, velocity and position are calculated for each time step. A separate stiffness matrix, damping matrix and mass matrix is set up for each individual element. This matrix depends on the batch function and the material used. The shape functions have an important role. By using these functions, it is possible to draw conclusions about stresses and strains from the calculated nodal displacements. Here, the relationship between the shifts in an element becomes apparent. The higher the degree of the interpolation function, as the shape function is also called, the more exact the result.

There is an implicit and an explicit time step method for the simulation calculations. The implicit method does not fix a time step. Here, not only the known variables at the beginning of a time step are included, but also those sought for the following time step. The equations of motion are calculated iteratively by calculating back from t + x to t. This calculates new values from the old and new values. [8]

The explicit time discretization uses time steps that have a given length. The time step size depends on the calculation accuracy and the calculation time because narrowing the time step width increases the accuracy of the results, but the calculation time increases in return. The accuracy increases, but only up to a certain limit. Narrowing the time step then does not lead to any further improvement. In general, the time steps should be chosen so that they are smaller than the meshing of the elements. An advantage of the explicit method compared to the implicit method is the lower performance requirement of the computer systems. Likewise, non-linear phenomena (e.g. contacts between two components) can be calculated more easily. The advantage stems from the fact that no systems of equations have to be solved. With the advantage also comes a disadvantage. The explicit method can only be used for relatively short computing times. For large time steps, the implicit time integration provides more accurate results, which are, therefore, very stable. For this reason, the implicit method is used for linear or weakly non-linear problems.

This research is a crash simulation with occupant models. In crash simulations, non-linear dynamic processes occur with a short duration of action. Accordingly, the explicit time discretization is used. In the event of vehicle collisions, the stresses that occur are not used as the main source of information since the plastic strains and the deformation energy absorbed (internal energy) are of greater importance. In the course of deformation, elements can become "smaller". This influences the critical time step since it becomes smaller and the computational effort increases. However, the critical time step can be almost completely compensated with the help of so-called "mass scaling". The basis is the scaling of the density and thus the mass. As a result, the speed of sound, which is dependent on the density, decreases and the time step remains the same. This procedure creates certain calculation errors that are negligible within a certain framework.

Crash simulations are multi-body systems. There are a large number of different components and bodies with which the calculation is started. The contacts form the basis for the optimum functioning of the simulation. It is necessary that each individual component has a self-contact. This makes sense so that a component can come into contact with itself and the kinematics can be reflected realistically. The different components are only able to influence each other if contacts between them are defined. Otherwise, these components can be moved freely in space and penetrations are visible. With these contacts, each node of the contact surface (master) is checked in each calculation step to determine whether it is in contact with an element of the target surface (slave). In order to solve convergence problems, the penalty formulation is used in crash simulations, among other things. This algorithm allows for a certain overlapping of the contact surfaces. In return, a spring force that depends on the contact stiffness is applied to the nodes that come into contact. This power is called the penalty power. Depending on the type of stress and the problem, different types of contact are possible. It is possible to define several components of a simulation at the same time with a further number of components with one contact. This is necessary and useful for complex occupant simulations.

4.2 Loadcase Definition

When analyzing and evaluating the results, only the restraint systems of the respective load case and the dummies are evaluated with regard to certain criteria. Furthermore, there is no evaluation of unstrapped load cases. In addition, there is no provision for an evaluation of the passenger or the occupants in the second row of seats. So this research only deals with the driver's seat side. In order to best represent the influence of swivel seats, care was taken to select the critical loadcase.

There are two types of frontal impact: impact with a rigid wall and deformable barrier with an offset. The crash with a rigid wall is consequently the impact with the maximum forces and deformations, because the wall does not allow any deformation and accordingly no energy dissipation and the energy flow is completely guided through the vehicle. In contrast, the impact with a deformable barrier converts part of the kinetic energy that occurs into deformation energy and thereby lowers the part of the kinetic energy that has to be converted into deformation energy by the vehicle body. A uniform, comparable evaluation with simultaneous high stress for the occupant is only guaranteed by the load case with the impact on a rigid wall, since the positions of the dummy and the seat are not only linked to a uniform pivot point, but also to a translation. The position of the occupant would move further and further into the interior of the body and thus strong local deformation would escape. For this reason, only the loadcase with impact on a rigid wall is considered in this work. [9]

4.3 Seat Position Definition

To investigate the influence of swivel seats on the restraint systems, the seat positions to be analyzed must first be narrowed down. Already in Chapter 3 when introducing existing vehicle concept studies, the maximum angle of rotation used is opposite to the normal direction of travel. *Figure 7* shows a matrix according to which the different swivel seat position variants are named in this work.

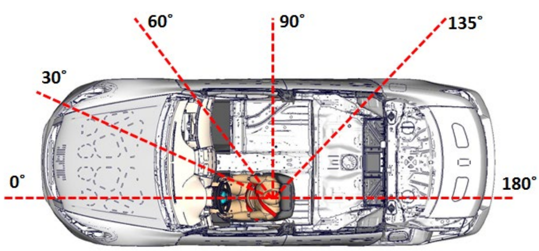

Figure 7
Representation of the examined angles of rotation (Source: Author’s plot)

The area examined extends from 0˚, which corresponds to the current driver's seat position, to the 180˚ position, in which the driver's view is directed towards the rear. In order to limit the number of variants that are examined, the angle steps are limited. As part of this thesis, the 0˚, 30˚, 60˚, 90˚, 135˚, 180˚ positions of the seat are examined in more detail and examinations are carried out on the basis of these variants.

The selected rotation points can be seen in *Figure 8*. The verification takes place by building up the various angles of rotation for each point. The result shows that rotating the driver's seat without adapting the vehicle interior is impossible. In addition, it can be seen that a single rotation around a selected pivot point is not sufficient to control the selected rotation angle, because depending on various degrees of angle, the seat overlaps with the vehicle environment, in particular with the steering wheel and the B-pillar. An adjustment of the position of the steering wheel and the B-pillar are impossible due to large geometrical interventions.

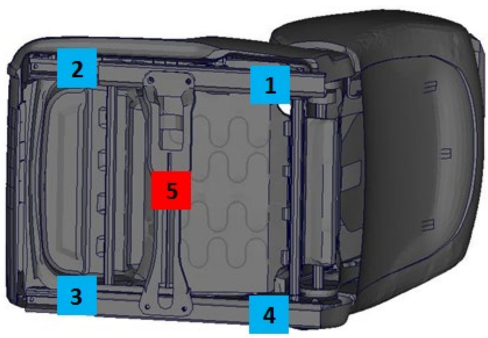

Figure 8
The examined rotation points of the seat console (Source: Author's plot)

To remedy this, two translations are introduced in combination with the rotation. The translations of the seat and the dummy on it ensures a sufficient distance from the steering wheel and the B-pillar. The fifth rotation point is used as the starting point for the rotations and translations. The starting point for determining the appropriate translations is the 90˚ sitting position. The head position is controlled accordingly with the aim of an exact impact on the driver's airbag. Starting from this 90˚ base position, the translations of the other angular positions are determined using a linear dependency. The proportion calculation is demonstrated using an example. The 90˚ position represents 100%, so 30˚ are considered a third of the base. Consequently only 30% of the translations that are used in the 90˚ position are to be applied to the 30˚ position. [10]

4.4 Adaptation of the Vehicle Model

For the following investigations, the Honda Accord model is adapted to the loadcases of the respective crash type. For a front impact, a rigid wall is placed in front of the vehicle model and the Honda Accord is hit at a speed of 50 km/h. It should be noted that the wall and the vehicle have a 100% overlap.

The simulation model is a conventional vehicle. Accordingly, measures are to be determined that lead to the elimination of the lack of space inside the vehicle. In order to generate the space taken up for the rotation of the seat, the front passenger seat is removed at the beginning. The second step is to remove the entire center console of the vehicle. This is what makes it possible for the first time to apply a rotation to the driver's seat without penetrations. In Chapter 3, no center consoles can be seen in the concept studies presented in the area of the driver and front passenger. The adaptation of the interior is marked in *Figure 9*. [11]

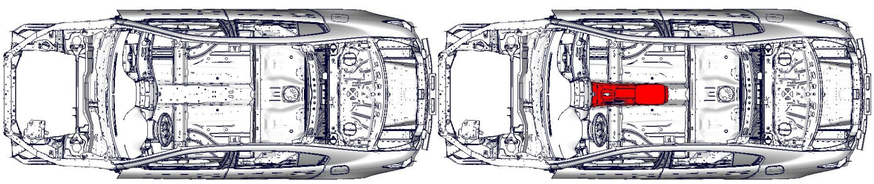

Figure 9
Base model (left) and adaptation (right) (Source: Author's plot)

In addition, the underbody of the vehicle model must be adapted to the boundary conditions so that it is possible to turn the driver's seat into the respective rotational positions. In order to gain space-related advantages, the tunnel to which the center console is attached is flattened. Electric vehicles are often associated with driverless driving. In the case of electrically operated vehicles, the exhaust gas system is omitted due to the lack of exhaust gases, as is the tunnel designed for this purpose, if this is not used for cooling. In addition, in current vehicle models, the battery, energy storage, is attached below the underbody. *Figure 10* shows the geometric changes made to the sub-floor. [12]

Figure 10
Geometric adaptation of the sub-floor (red: base; blue: adaptation) (Source: Author's plot)

In addition to the points mentioned above, it is essential to adjust the seat. In every vehicle, the seat is attached to the so-called seat cross members, which give the seat the necessary stability with regard to various accident scenarios. As a rule, current vehicle models have two seat cross members, but the Honda Accord model is one of the vehicle models that only have a single seat cross member. As part of this research, fastening the seat console to the seat cross member by rotating the seat is neither sensible nor possible, as massive lever arms occur and would influence the calculation. The task of the seat cross member is to connect the seat to the vehicle body via its seat console, thereby ensuring the restraint effect and the flow of forces. For this research, the seat is connected to the underbody of the vehicle for every rotation and translation. Accordingly, a separate mounting base is created individually for each angle of rotation in the interval from 0˚ to 180˚. This creates an optimal anchoring of the seat console on the underbody in the simulation model. [13]

An essential change to the present model is made in the attachment of the belt. The seatbelt is usually anchored in the B-pillar due to the large amount of force exerted, but the driver's seat cannot be rotated with the belt attachment as the belt would tighten the occupant's neck. For this reason, the seatbelt holder is integrated within the seat. A change in the direction of force flow and an additional load on the seat are to be expected. The changes are shown in *Figure 11.* [14]

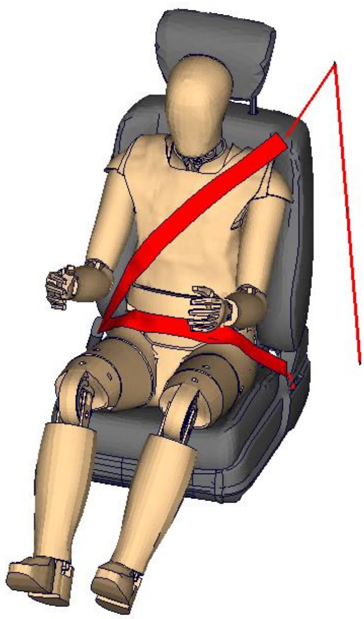

Figure 11
Geometric adaptation of the seat belt (Source: Author's plot)

5 Results of the Simulations

In the following chapter, an overview of the results of all examined angles of rotation during a frontal crash is presented. Only the driver side position was examined during the simulations. On the basis of this preliminary investigation, certain trends can be established for certain properties of the angle of rotation. In the further course of the process, the resulting abnormalities are substantiated by a detailed examination of the dummy kinematics and the consumer protection criteria. This is necessary in order to make a selection from the simulations used for further investigations. Critical load cases are then selected on this basis. The comparison of the simulations is made in connection with the most important evaluation criteria. [15]

In order to provide an overview of the examined seating positions, the measuring dummies are divided into the load cases. In order to get a first impression of the determined results, the evaluation takes place with the help of the limit values of the most important Euro NCAP criteria. For the angle ranges from 0° to 90°, the driver airbag is ignited with an ignition time of 14 ms. On the other hand, there is no ignition of the driver airbag in the area of the rotation angle from 135° to 180°, since the effective range of the airbag is significantly restricted by the seat backrest and a large part of the protective effect is lost. The results of the sitting positions for the angles of rotation from 0° to 180° are shown on *Table 1* and *Table 2*. The following tables show the results of the simulations with the adopted model.

Table 1
Results overview (yellow = maximum value)

Criteria	Limit value	Unit	Simulation 0°	Simulation 30°	Simulation 60°
Head (HIC15)	700	[-]	487	1159	964
Head (a3ms)	80	[g]	55,1	91,3	93,1
Head (BrIC)	1,05	[-]	0,57	0,93	0,95
Neck (Nij)	0,85	[-]	0,43	0,59	0,48
Chest (Compression)	60	[mm]	41,4	50,6	54,9
Abdomen (Compression)	88	[mm]	68,1	113,4	103,5
Femur (Force)	7,56	[kN]	6,88	4,39	6,11

Table 2
Results overview (yellow = maximum value)

Criteria	Limit value	Unit	Simulation 90°	Simulation 135°	Simulation 180°
Head (HIC15)	700	[-]	833	803	731
Head (a3ms)	80	[g]	83,3	75,3	72,9
Head (BrIC)	1,05	[-]	1,74	1,43	1,18
Neck (Nij)	0,85	[-]	0,57	0,63	0,61
Chest (Compression)	60	[mm]	48,3	46,1	56,7
Abdomen (Compression)	88	[mm]	91,4	78,6	71,4
Femur (Force)	7,56	[kN]	6,32	8,17	7,26

6 Validation of the Simulations

It is absolutely necessary to use a real test to validate the simulations. The simulations were based on the 2008 model of Honda Accord, therefore, requisite to use the real test of this model as a basis for validation. For this front impact test, a rigid wall is placed in front of the vehicle model and the car hit at a speed of 50 km/h with 100% overlap.

The tested model of Honda Accord Euro was introduced in Australia during 2008. Dual front airbags, side airbags and head-protecting side curtains are standard equipment. Antilock brakes (ABS), electronic brake distribution (EBD) and electronic stability control (ESC) are also standard. Intelligent seatbelt reminders are fitted to all seats. The front seatbelt buckles are mounted on the seats and the upper anchorages are adjustable. These features improve the fit of the seatbelt. Pretensioners are fitted to the front seatbelts to reduce slack in the event of a crash. A three point seatbelt is fitted to the centre rear seat. This provides better protection than a two point seatbelt. [15]

The Accord Euro scored 14.47 out of 16 in the frontal crash test (5 Stars). The passenger compartment held its shape well. There was a slight risk of serious chest injury for the passenger and a slight risk of serious lower leg injury for the driver and passenger. Body region scores out of 4 points each: Head/neck 4pts, chest 3.45pts, upper legs 4pts, lower legs 3.02pts. The accelerator pedal moved rearwards by 41 mm. The steering wheel hub moved 20 mm forward, 13 mm upward and 7 mm sideways. The front A-pillar moved 16mm rearwards. All doors remained closed during the crash. After the crash all doors could be opened with normal effort. The airbag cushioned the head of the driver and contact was stable. There were no knee hazards. The passenger's head was cushioned by the airbag.

Maximum points were scored for protection of the 3 year infant based on the dummy result from the impact tests. The passenger airbag can be disabled to allow a rearward-facing child restraint to be used in that position. However, information presented to the driver regarding the status of the airbag is not sufficiently clear. A warning label clearly warns of the danger of using a rearward facing child seat in the passenger seat without first disabling the airbag, but the information is not available in all European languages. The presence of ISOFIX anchorages in the rear outboard seats is not clearly marked.

The bumper scored maximum points for the protection offered to pedestrians' legs in the area rated by Euro NCAP. However, additional tests showed that some areas beyond the central zone provided poor protection. Most of the zones tested in the area of the bonnet where a child's head might strike also scored maximum points. However, the front edge of the bonnet was rated as poor.

Figure 12

Honda Accord 2008 EUNCAP Crash Test [16]

Table 3 shows the results of the base model and the modified model in comparison with the crash test. The base model is validated, it can be seen that all differences in the simulation results remain within the 10% limit. The situation is different for the fitted model, due to the attachment of the belt in the seat and the associated reduced restraint effect. This results in a significantly changed kinematics of the seat and the dummy and the results also show a partially larger difference compared to the crash test. There is a bigger difference in the values of the neck and chest, the main reason for this is the change of the seatbelt. The fitted model should be used for comparison with rotated seat variants, all modifications are summarized in Chapter 4.4.

Table 3
Results of the base model and the modified model in comparison with the crash test

Criteria	Unit	Limit value	Crash test	Simulation 0° Base model without any modifications	Simulation 0° Fitted model with all modifications
Head (HIC15)	[-]	700	416	437 (+5%)	487 (+17%)
Head (a3ms)	[g]	80	47,4	49,4 (+4%)	55,1 (+16%)
Neck (BrIC)	[-]	1,05	0,39	0,42 (+8%)	0,57 (+46%)
Neck (Nij)	[-]	0,85	0,64	0,63 (-2%)	0,43 (-32%)
Chest (Compression)	[mm]	60	32,8	34,3 (+5%)	41,4 (+26%)
Abdomen (Compression)	[mm]	88	72,9	70,7 (-3%)	68,1 (-7%)
Femur (Force)	[kN]	7,56	6,03	6,25 (+4%)	6,88 (+14%)

Conclusion

The aim of the research was to create a computer simulation model suitable for testing the passive passenger safety of a fully self-driving vehicle. The computer model was validated with measurements and transformed in such a way that it is suitable for testing the desired seating positions. We examined to what extent the seating position of the passengers affects their injuries in the event of an accident. During the tests, the results of the injuries that occurred in the case of seat positions turned by 30°/60°/90°/135°/180° we compared with the case of the driver's seat in the normal basic position. We pointed out that the kinematics of the driver's movement during an accident changes radically as a result of modified seating positions. We have proven a large reduction in the effectiveness of traditional passive protection systems, and the chance of fatal injuries increases significantly in the case of rotated seating positions. This applies primarily to head and neck injuries, but the impact value of the chest and the extent of leg injuries also become more serious.

That is why it is necessary to expand the passive protection systems known today. Our goal is to create a system that provides effective protection even in the case of rotated seating positions. We examine the possibilities of further developing the driver's seat from the point of view of passive vehicle safety, what kind of protection it could provide for the fully self-driving car of the future. The seat must be able to coordinate the movement of passengers in the event of an accident, even in rotated seating positions, and must be involved in preventing serious injuries. We build a model to test and verify this.

In addition to the above, we would like to investigate new possibilities for the use of airbags in self-driving vehicles. In a vehicle without a steering wheel, the airbag for driver protection can be imagined in a radically new position, size and shape. We determine which direction of change affects the driver's injuries in the event of an accident.

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