Optimization of a Cockpit Structure according to ECE-R21 Regulation

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Keywords:
Crash, ECE-R 21, Cockpit, Interior fittings, Head impact, Component Model, Optimization

ABSTRACT

For a prototype of the new LANDROVER cockpit, developed by Siemens VDO Automotive, the design of the co-driver airbag area had to be optimized with the help of simulation in order to fulfill the guidelines of ECE-R 21. Furthermore a more limited inhouse-target had to be reached.
The actual state of the prototype was illustrated by simulation and the influence of different measures on the crash behavior was examined.

Among other things the following modifications were accomplished:
- Changing the stiffness of the instrument panel by specific design of the rib structure
- Reducing the stiffness of the airbag box and its connections
- Partial absorption of the impact energy using foam depositors between instrument panel and airbag unit

The influence of different strategic ways to optimize the crash behavior, in respect of head impact will be shown on a simplified cockpit model. Finally, a comparison of the simulation and the testing of the new RANGE ROVER cockpit will be given.

INTRODUCTION

The regulation ECE-R 21 contains the "uniform provisions concerning the approval of vehicles with regard to their interior fittings". A part of this regulation contains defaults for the arising deceleration for an occupant head by impacting structure parts of a cockpit. A steel ball is used as test piece. For the acceptance test a maximum deceleration of 80 g during a continuous duration of 3ms may not be exceeded. At these tests it usually comes to damages of the cockpit, which causes high set-up times and costs at larger test series. Furthermore in face of modern measuring technique only the results after the test are assessable. The insight of the actual kinematics at the impact and thus the basic information for a possible improvement mostly remain in identified. Here the simulation can supply a substantial contribution for a better analysis of the kinematics at a crash and compile and evaluate improvements based on them.
Targets of the use of simulation are time and cost saving by a fast variant formation, without the problems of the availability of the parts for the test of the cockpit.

Guidelines from the ECE-R21

The ECE (resp. UNECE) is the United Nations Economic Commission for Europe. It specifies regulations for uniform minimum standards in its member countries, which have to be fulfilled during the permission of motorcar types.
The regulation ECE-R 21 contains uniform provisions concerning the approval of vehicles with regard to their interior fittings.

The scope of this regulation contains:
- interior parts of the compartment (excluded rear-view mirror)
- arrangement of the controls
- roof and sliding roof
- seat-back and rear part of the seats

The defined reference zone shall exhibit no dangerous roughness or sharp edges likely to increase the risk or severity of injury to the occupants.
Basis for the verification is a sphere with a diameter of 165mm that will roll off on the cockpit. Parts, which cannot be contacted by this sphere, will not be verified for their surface integrity.
In addition for fulfillment of the ECE-R 21 the cockpit has to pass a head-impact test. The head-impact zone comprises all the non-glazed surfaces of the interior of a vehicle, which are capable of entering into static contact with a spherical head 165mm in diameter. This is an integral part of a measuring apparatus whose dimensions from the pivotal point of the hip to the top of the head is continuously adjustable between 736mm and 840mm.

The head form shall strike the test component at a speed of 24,1 km/h or with 19,3 km/h at parts, which contain a non-filled airbag (e.g. impact on the airbag cap).
The test apparatus consists of a pendulum whose reduced mass at its center of percussion is 6,8 kg. The lower extremity of the pendulum consists of a rigid head form 165mm in diameter whose center is identical with the center of percussion of the pendulum.

Figure 1: testing facility for head-impact at the company SiemensVDO Automotive

After an investigation the certification authority decides about the positions of the head impact points in the defined reference zone.

Possible points of impact can be:
- Hard structures at the surface (material or form stiffness)
- Locations with solid parts behind the cockpit covering (e.g. carrier structure, airbag box...)
- Locations where material fracture or disruptions are to be expected. The occurrence from sharp edges in the case of the impact is not permissible.

In these kinds of head impact tests, the deceleration of the head form shall not exceed 80g continuously for more than 3 milliseconds. In practice in addition within the range of ± 1.5 milliseconds around a peak value (maximum peak) the average

value (3ms-value) for the deceleration is built. This shall not exceed a value of 80 g. Here the peak value of the deceleration curve has to be selected, where the highest 3 ms-value occur. At deceleration curves with several peaks, this need not be inevitably the peak with the maximum deceleration-value during the complete impacting procedure!
The occurrence of sharp edges in case of the head impact is not permitted because of the injury risk, especially in the case of a possible secondary impact. To check this there is a visual inspection after the impact test.

Model build up

Basis of the view is the new RANGE ROVER cockpit developed by Siemens VDO Automotive. In order to fulfill the guidelines of ECE-R 21, beside the build-up of the prototypes of the cockpit by the test department, successfully the tool of simulation was used. Exemplary the procedure is pointed out at a principle model developed by Ingenieurbüro Huß and Feickert, where the situation presents itself similarly to the real cockpit.
The calculation of the cockpit model was done with the explicit program code LS-Dyna, which is used predominantly in the short time dynamics and crash simulation for highly nonlinear systems.
For the head impact on cockpit structures all relevant parts for a crash, up to the cross beam, usually will be mapped in the simulation-model.
In the here used principle model (see Fig. 2) for an impact on the co-driver airbag area, the following components are made out of plastic: instrument panel, glove box with cap, airbag cap and parts of the center console.
In steel implemented components are: the ip-beam with brackets, as well as airbag box and airbag nozzle

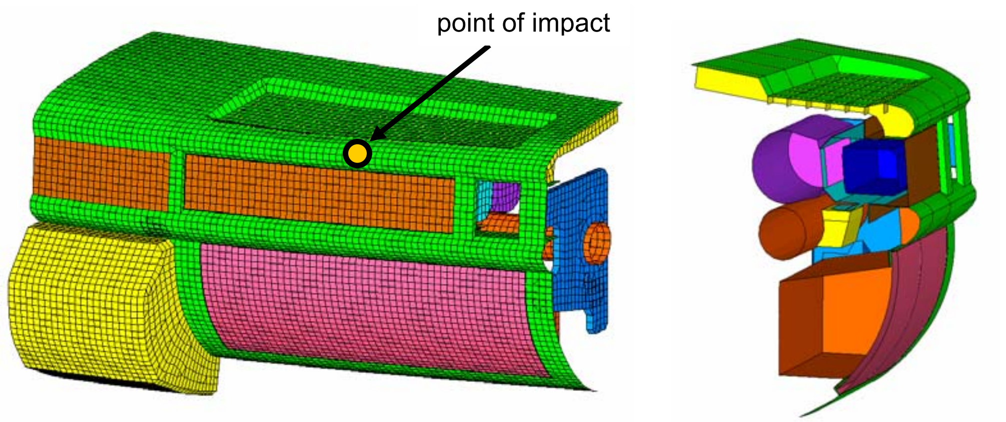

Fig. 2: Used FEM principle model of a cockpit structure

If the impact point is in the outside range, a half model can be used to reduce the computing time, because of only small deformations at the range of the center plane. In such a circumstance the structure nodes on the center plane can be symmetrically guided. Tests showed that this procedure supplies a good accordance with the complete model. To validate the half model an alignment with the complete model takes place, before and after the optimization.
Due to the fact that the points of impact are distributed all over the complete cockpit, it is advisable to use a consistent fine meshing for all parts. Due to the small model

size of a component model and the associated short computing times, element edge lengths from 4 to 6 mm are recommendable. The shell elements were represented as BELYTSCHKO TSAY elements (type 2). With this type of elements there is a stable operating behavior, even with larger distortion of the elements.
For steel as well as for plastic materials the material law *MAT_PIECEWISE_LINEAR_PLASTICITY (type 24) is used. The dynamic material behavior is considered by different stress-strain-curves at different strain rates (*DEFINE_TABLE). In some of the variants a foam pad comes into operation to absorb the impact energy. The foam pad is represented as volume model with HEX8/PENTA6 elements.
In order to improve the contact definition the individual volume elements were additionally encased with shell elements. These shell elements get assigned the material law * MAT_NULL (type 9). So they do not have physical characteristics and therefore the stiffness of the foam outline does not be affected.
Only slight deformations are assumed at the range of the a-pillar connection to the cockpit cross beam, so the model is fixed at the connection points with a *MAT_RIGID (type 20) with limited degrees of freedom. Also the border area of the cockpit, which join on neighboring structure parts of the vehicle, are constrained similarly.
The connection elements of the single components among each other are differently modeled, depending upon the kind of the connection. At relatively stiff connections (e.g. spot welds, rivets or screw connections) rigid connections or beam elements are used. At resolvable or softer connections, clips-connections for example, spring elements are used (possibly with tear criterion).

A hemisphere is used as impactor . In the ECE-R21 a rigid test piece is specified, so it is defined as *MAT_RIGID. The impactor receives its initial speed from a *PART_INERTIA. With this card also the guidance in axis direction is realized. The radius of the circular path which the impactor is moving on, remains unconsidered in the simulation, because of the almost linear movement due to the large pendulum length and the small penetration.

Basic model

The examination is based on a first design concept of the cockpit structure. The considered point of impact is located on the front edge of the instrument panel towards the co-driver (see Fig. 2). The instrument panel is provided with a rib structure for reinforcement. Directly underneath the instrument panel the airbag module is placed, which will be hit in case of a head-impact.
The front edge of the instrument panel is very stiff because of a ribbing on the backside. Furthermore there is a support between instrument panel and airbag unit. (see Fig. 3). This leads to a rapid increase in the deceleration curve. Deformation of the upper section of the instrument panel and the underlying rib structure can be observed. After approximately 3.5 ms a displacement of the ip-beam can be observed. This leads to smaller deceleration values and to a flatter upward gradient in the deceleration curve. After approx. 5 ms there is a contact between the rib structure at the instrument panel and the upper border of the airbag box, which serves the fastening of the airbag cap. The system runs on block and the deceleration curve rises more steeply. With approximately 7.0 ms the bouncing of the impactor (maximum way) begins.

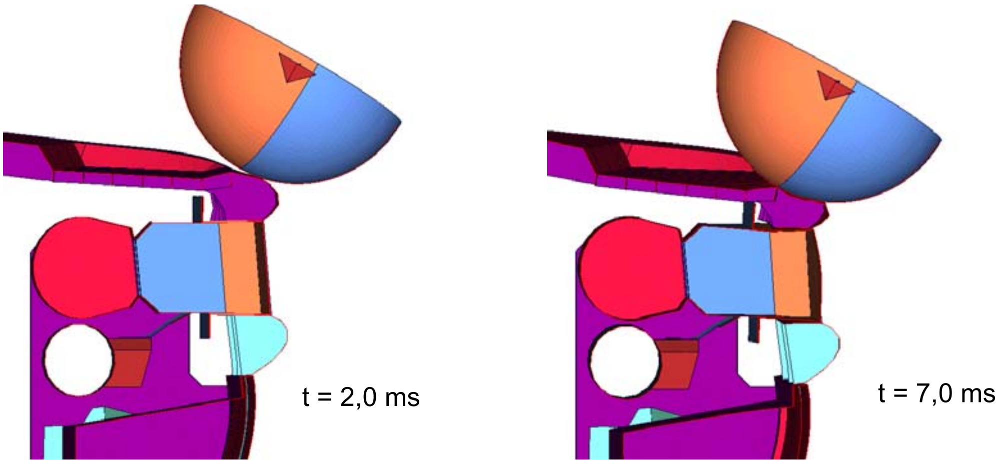

Fig. 3: Deformation pictures of the basic model at 2,0 ms and 7.0 ms (max. penetration)

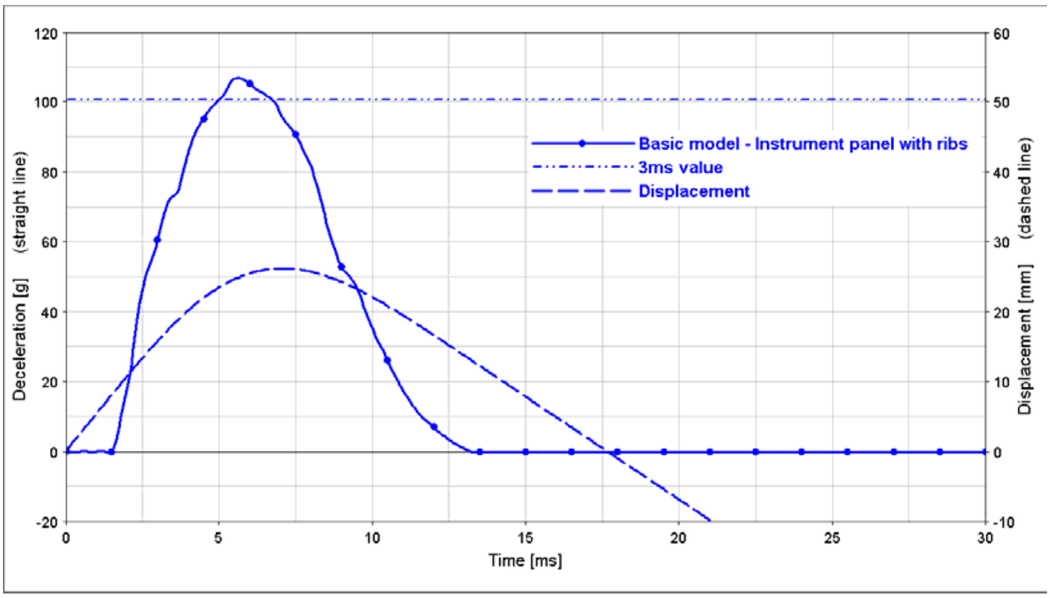

Fig. 4: Simulation results of the basic model

This basic design has a maximum deceleration within the range of about 105 g. The 3ms-value for the deceleration is up to approx. 100 g. These values did not pass the ECE-R 21 guidelines. Measures must be taken, in order to reduce the deceleration values.

Variants

There are different solution types to keep the limit values demanded by ECE-R 21. Measures can be brought into the system, which provide a reduction of the deceleration and of the energy to a low level.
These measures can be the usage of a weaker structure, which allows more deformation for the impactor, or the usage of foam depositors. An alternative possibility consists in degrading of the energy at high level of deceleration at a stiff structure (e.g. using a steel depositor) within a very short period of time.
Also the deceleration can be specifically controlled. This can be achieved with material failure using rated break points. So it could be achieved that for a short period much energy is degraded on high level and at the following break-down (failure of the rated break point) the 3ms-value remains under the demanded limit value.

Exemplary the deceleration at the principle model will be lowered by the following variants:

- Trimming of ripping at the backside of the instrument panel
- Degradation of the stiffness of the airbag box
- Bring in a foam structure between instrument panel and airbag box

These 3 possible solution methods are pointed out, related to the basic model.
To complete this examination a combination of several measures in one model will be shown.

5.1 Modification of the structure of the instrument panel

In order to reduce the deceleration curve of the basic model, in a first step the rib structure at the backside of the instrument panel is trimmed. This is to induce that the front edge of the instrument panel will become "softer" and as a consequence more impact energy is converted promptly into deformation energy. In order to get the maximum obtainable reduction, which can be reached by a modification of the ribbing, there was an additional computing run completely without ribbing.

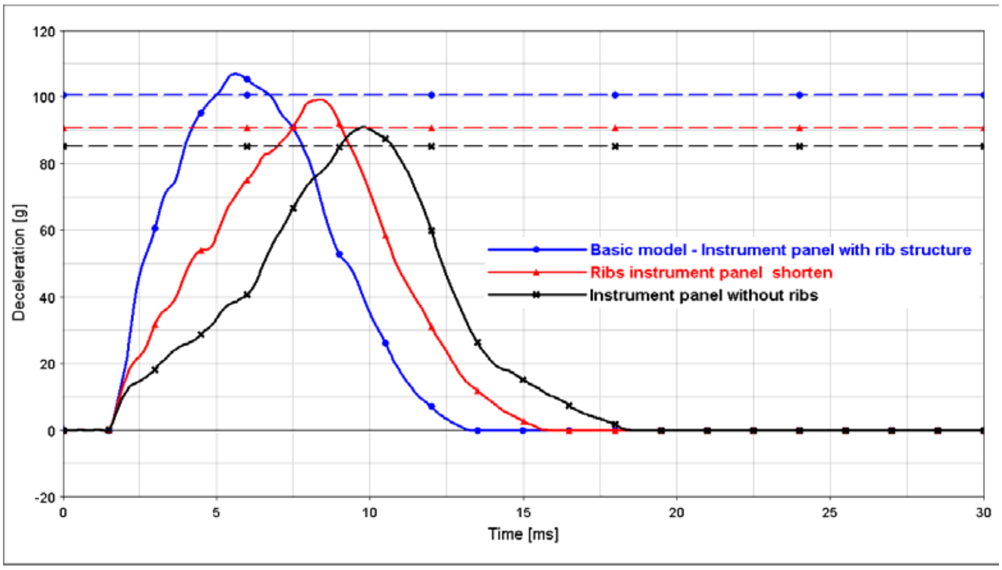

Fig. 5: Pulse curves for change of the instrument panel stiffness

By a trimming of the rib structure and the associated "softer" impact edge, there is a flatter rise in the deceleration curve at the initial range as expected. The time flow of the impact procedure extends by the softer structure and the energy degrades over a larger way of penetration. The maximum peak of deceleration is lower and will be reached about 3 ms later.
Complete removing of the rib structure induces a still flatter rising deceleration curve with lower maximum value. But even in this case the 3ms-value for the deceleration is still lying above the limit value of 80 g, which is required by the ECE-R 21.
Only by modification of the rib structure the limit value cannot be reached. Further measures to reduce the deceleration values must be taken.

Modifications of the stiffness of the airbag box

In the past variants it was recognized that the airbag module itself behaves very stiff. So the prefaced energy passes through the brackets nearly directly over to the also very stiff ip-beam. This stiff structure is responsible for the height of the deceleration values. The stiffness of the airbag box is caused by a L-profile at the top and bottom side, which is used for the fixing of the airbag cap. Within these variants the L-section in the center is cut out in order to reduce the stiffness and to enable more displacement to relieve the energy. So for the fixing of the airbag cap only four latches are remaining.

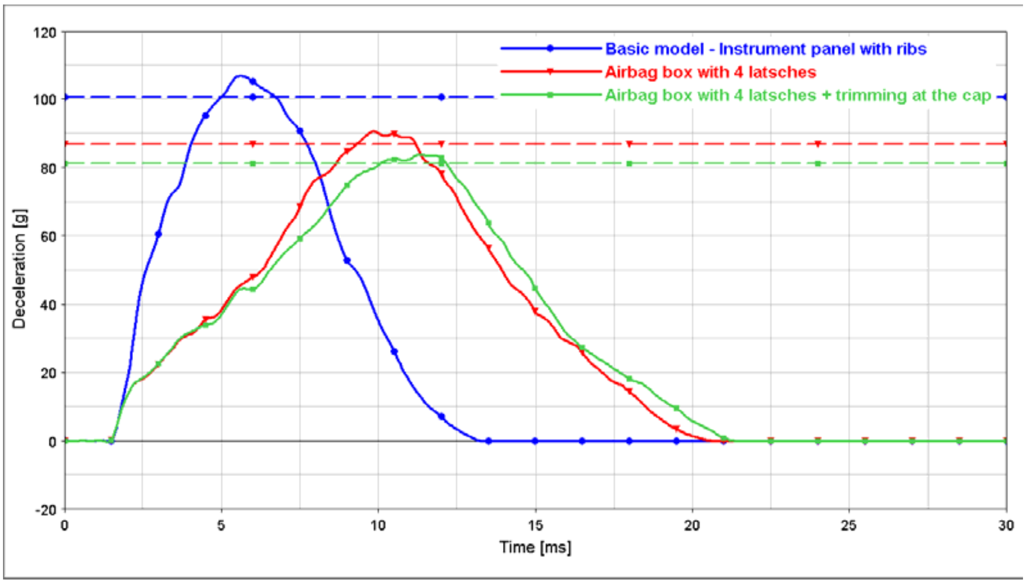

Fig. 6: Deceleration curves for changing the stiffness of the airbag module

Basis for this investigation is the variant with ribbing at the instrument panel. There are only small deformations at the airbag box, because of the applied L-profiles. The instrument panel is support by this L-profile. By trimming the L-profile an early blocking is prevented and more displacement for the head form test piece is possible to degrade the energy. An additional trimming of the airbag cap also allows more displacement for the test piece. This provides an additional reduction of the deceleration. But only the softer structure of the airbag unit is insufficient, in order to fall below the demanded limit value.

Bring in a foam structure between instrument panel and airbag box

In this example a polypropylene foam (EPP) is used. This foam is characterized by high energy absorption with small weight and good recovery after static and dynamic loading. The stiffness of the material is essentially adjusted by the producer over the density.
The stress / strain behavior depends on the speed which the load is applied with. With an increasing rate of load application the material behaves more rigidly. In our example variants of the foam depositor with a density of 60 g/l and 30 g/l are used.

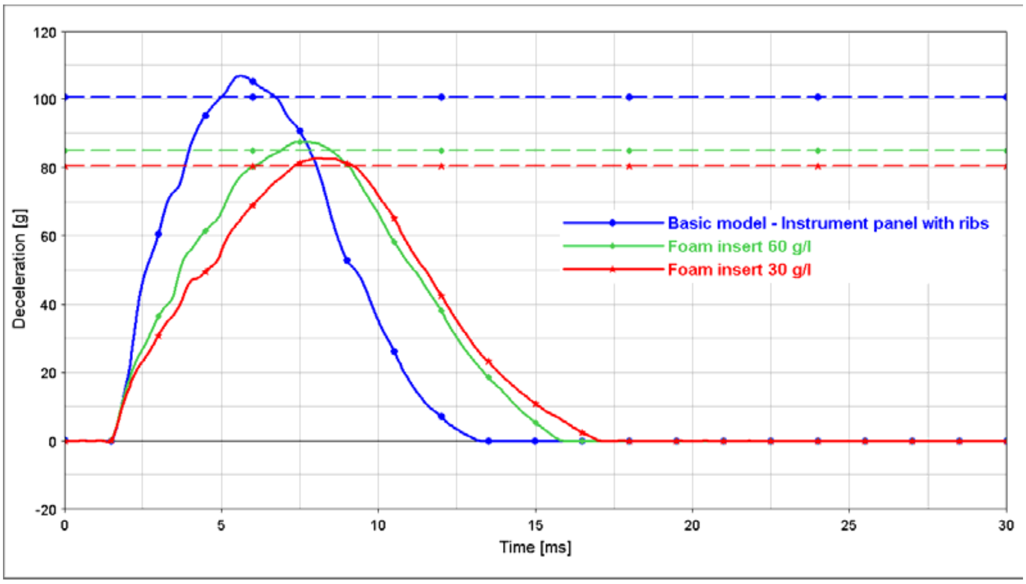

Fig. 7: Pulse curves with variations of foam inserts

With a foam insert of 60 g/l foam the 3ms-value is still over the limit value of 80 g, which is demanded in the ECE-R21. Already by using a foam insert of 30 g/l the value is directly in range of the limit value.
The softer 30 g/l foam becomes more compressed in the case of the impact (see Fig. 8). Therefore we get a better absorption of the energy by the foam.

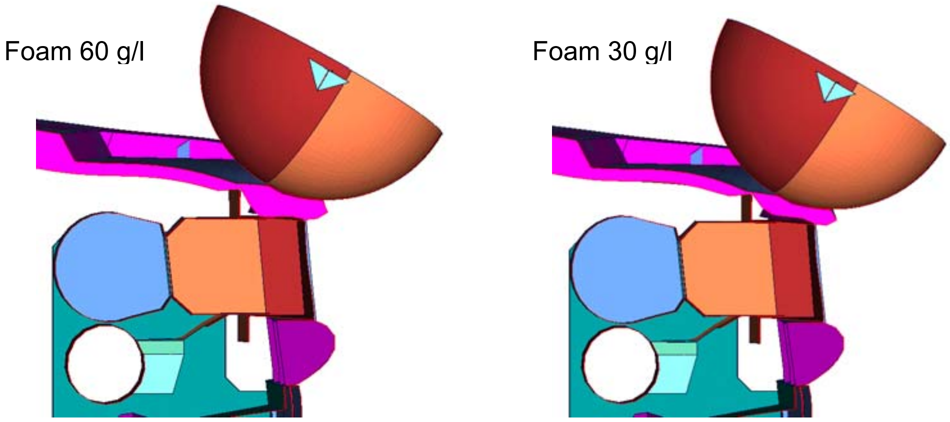

Fig. 8: Deformation pictures of the variants with foam insert at maximum compression

5.4. Combination of measures

Usually one measure is not enough to obtain the desired success. A number of different measures has to be combined. The combination of measures does not mean inevitably that deceleration values reduce by the sum of the individual measures. Therefore always an examination of the individual case is necessary. In this case the combination of a foam insert with a density of 30 g/l, a modified airbag box with 4 latches and a local trimming of the rib structure at the instrument panel is examined.

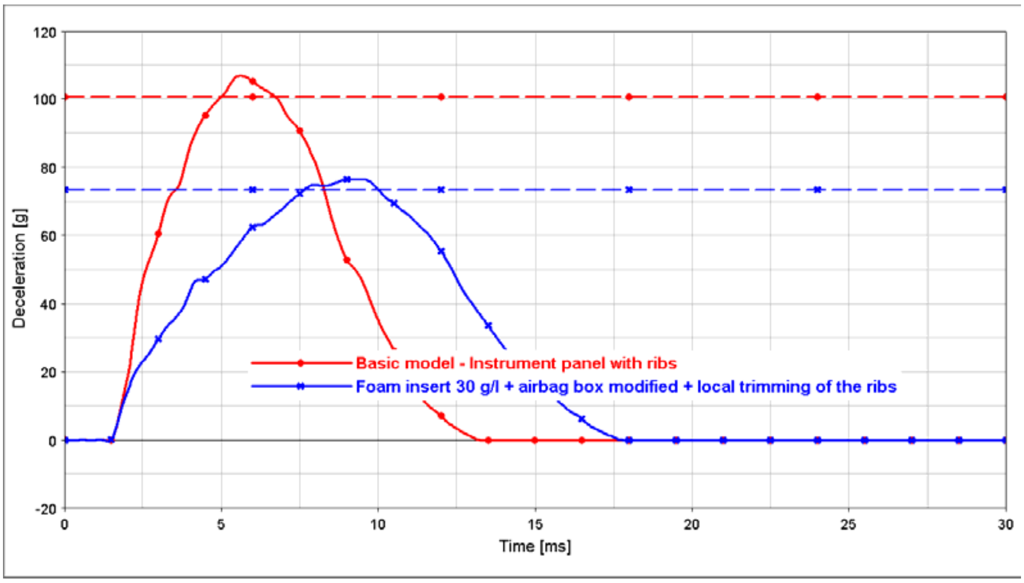

Fig. 9: Reduction of the deceleration by a combination of measures

While the single individual measures alone provide a still strongly marginal result, the combination obtains a 3ms-value of about 72g, which fulfills the guidelines of the ECE-R 21. In relation to the basic variant thereby an improvement of the 3ms-value of nearly 30% was reached.

Verification of the simulation by the testing

As a system supplier of the new RANGE ROVER cockpit, beside other things Siemens VDO had to guarantee the fulfillment of the guidelines from the ECE-R 21. Furthermore a more limited inhouse target for the 3ms-value of 72 g has to be fulfilled. Beside crash test at the cockpit additionally the simulation came into operation.

Fig. 10: Checkpoint for the head impact at the RANGE ROVER cockpit

Based on a first design concept a simulation model was developed, in order to point out problem areas for head impact and if necessary changes for the construction can be examined early.
The simulation supplied valuable references to the kinematics of the system by the possibility of defining arbitrary cross sections through the model and showing or masking specific parts of the cockpit structure. With first prototype parts parallel to the simulation first pendulum tests on the test range were accomplished. Based on these test results the computer model was optimized. A comparison of the results for an exemplary selected point of impact, shows good accordance between simulation and testing (see Fig. 11).

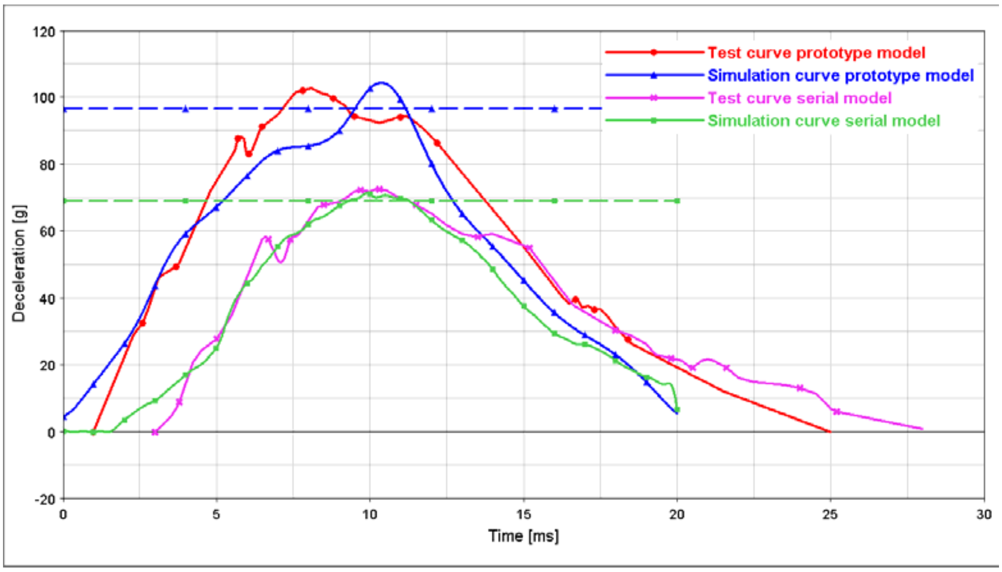

Fig. 11: Comparison of the results of simulation and test

A project team of Siemens VDO and Ingenieurbüro Huß & Feickert (ihf) evaluated these testing and simulation results and worked out possibilities for optimization.
By the use of simulation within shortest time improvements become pointed out based on the formed variants.

In spite of a very exact mapping of the real structure in the simulation, however there are also always deviations between simulation and test results. Some reasons are inadequacies in the description of the material indices, the connections and the boundary conditions. In addition, it can be justified by the usage of prototype parts at the testing, whose quality sometimes strongly strew compared with the serial parts. Also not all parts of a completely equipped cockpit are described in the simulation model (e.g. cable harnesses). Therefore always a careful validation of the simulation results and a balancing to the test results is necessary. If no test results are present, no absolute numerical values can be determined. But at least improvement potentials can be pointed out with the simulation.

The use of simulation has been proved as helpful, to understand procedures in the inside of the system, because testing usually evaluate only the arisen damage after the crash test. Thus possible room for improvements could be pointed out and therefore time and costs could be saved, because of the fast and simple variant building by the simulation. Also the sharper inhouse target of 72g going beyond the ECE-R 21 could be fulfilled.

Summary and Conclusions

The first design concept of a cockpit structure should be optimized regarding the ECE-R 21 regulations for head impact.
Based on a principle model for a cockpit system it was pointed out that the system structure could be optimized by specific measures in accordance with the guidelines of the ECE-R 21.
In order to validate the simulation a final review with a comparison of simulation and testing for the concrete example of the new RANGE ROVER cockpit was carried out. This cockpit was developed by Siemens VDO Automotive and as their partner the Ingenieurbüro Huß & Feickert accomplished all crash simulations. The input of the simulation has been proved as a useful utility, to assist in understanding the procedures within the cockpit during the crash test. By the fast and simple variant building and early pointing out of potentials for improvements, the total development could be completed resources-optimized.

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