Modeling and Simulation of a Vehicle Crash Test

Salah Eddine Akrout*, Nissrine Mhaiti, Mohammed Radouani, Bensaissa El Fahime

Research Laboratory: Mechanics, Mechatronics and Control – L2MC, Research team: Multidisciplinary Engineering and Mechatronic Systems – IMSM; ENSAM MEKNES; Moulay Ismail University, Meknes, 5000, Morocco

Abstract

Nowadays, Automotive manufacturers face competing demands and challenges. On the one hand, there is a growing demand for reducing costs and weight, for saving fuel and for decreasing time to market, and on the other hand, an ever-increasing demand to improve the safety and comfort of occupants under conditions of complex driving and crash conditions.

In order to lower the costs of vehicle crash test, manufacturers use digital simulation to reproduce physical phenomena using computer tools. This method is now an integral part of the design and validation process of new cars. The simulation tools are more and more efficient allowing a very fine description of the phenomena.

The application concerns a digital vehicle model for a crash test that impacts the rear seat, using the finite element simulation method. The simulation will allow us to accurately predict the real behavior of the vehicle during the impact with a more detailed description of the characteristics of the parts, connections and materials. Finally, a correlation study between the results of the numerical simulation and those of the same experimental test will allow us to estimate the influence of the numerical modeling on the simulation results.

Keywords: Numerical simulation, Safety, Rear seat, Crash, Finite Elements Method, Correlation

1. Introduction

Automotive safety research is a multifaceted discipline, involving many actors and implementing a variety of techniques. This makes it one of the most regulated industries worldwide.

Numerical simulation is today a tool that is widely used during the different design and validation phases of automotive projects. It enables more precise evaluation of the behavior of structures and materials, saving automakers considerable costs. Finite element calculation remains one of the most powerful methods of numerical simulation because of its precision in solving differential equations that describe dynamic or static behaviors of physical systems.

During accidents, the rear seats of vehicles are usually subjected to severe impact from luggage, leading to frame deformation or even breakage. This increases the loss of rear seat passengers. Therefore, the rear seat, as a safety component aimed at reducing injuries and casualties, must provide some margin of survival for rear seat passengers in the event of a collision and prevent other carriers, such as luggage, from entering the rear seat.

In this paper, we started by designing a vehicle model based on the method of concurrent-engineering, which remains one of the most widely used and highly efficient methods for complex products. Then we performed a finite element numerical simulation. A correlation between the results of the numerical simulation and the physical tests is noticed, so an iterative work is carried out on the modeling to reduce these discrepancies and improve the numerical model.

2. Geometrical Construction of Vehicle Model

The design of a complex system such as a vehicle is very delicate. The product cannot be dimensioned all at once because it has thousands of parts that perform many functions and interact strongly. These parts contribute to the different performances of the vehicle: comfort, safety, and ergonomics, road performances (structure and mechanics). The manufacturing constraints are also very strong and must be considered throughout the design of the vehicle.

In this work, we used the method of the design cycle on V, which has become the standard development cycle in systems engineering, and more precisely on the organic design phase. This phase of the V cycle, based on two global and local approaches,
consists in carrying out the product-process study in simultaneous engineering of the different vehicle organs from:

- Specifications to be respected.
- Plans of final designs.
- Industrial constraints (internal and supplier).
- All the project objectives (cost, investment, diversity, etc.)

The design of the structure of the vehicle model must respect the specifications that define the services to be dimensioned, namely: crash, vibration, reliability, statics, endurance... Knowing that the crash service is the most dimensioning for the vehicle body, this is why we prioritize the achievement of this performance at the design phase, by adopting a strategy of prioritization of services.

Our numerical model has been designed according to specifications defined under Catia V5 software, starting with 2D sketches, after the realization of 3D parts. Then the assembly of all the parts with different connections (weld beads, welding point, glue beads...).

Figure 1 illustrates the complete numerical model and the rear part of the meshed and assembled vehicle.

Figure 1: Numerical model of the complete vehicle

A simulation with the finite element method will be studied afterwards, in order to analyze the dynamic behavior of the numerical model during the crash-test and to propose improvements on the modeling [3].

3. Finite Element Simulation on Vehicle Numerical Model

Numerical simulation is therefore an efficient way to predict the outcome of a physical experiment, and in some cases to be able to do without it. Better still, simulation provides access to important information that is not possible or too expensive to measure in a test.

Vehicle crash simulation is probably the largest application of crash simulation. It started with very simple models based on spring mass damping systems, when computers and calculation servers were very slow and less developed. Today, finite element calculation software is available, integrating safety elements such as belts and airbags, as well as dummies to accurately simulate the behavior of occupants in various crash situations [4].

Fast dynamics in large displacement is a field of mechanics known for the strong non-linearity of physical phenomena, and their variability with respect to small parameter variations [5].

The static or vibratory behaviors of the structures are well approximated with behavioral laws that remain in the elastic range of materials. But the crash stresses the structures in their plastic domain. The equations of motion are then no longer linear, which results in complex responses. These highly non-linear behaviors complicate the search for a solution at a lower cost.

3.1. Procedures and approach used in finite element simulation

The finite element method applied to fast dynamics a problem differs from the classical finite element method in particular[6] by:

- A specific definition of finite elements with a well-specified mesh.
- Specific formulations and resolution schemes adapted to large deformations.
- Material laws integrating sensitivity to strain damage and fracture rates.
- Elements to control, for example, the behavior of assembly areas (welding points, adhesive beads, etc.).
- A good management of contact and interfaces (of the elements between them).

3.2. Meshing criteria

Meshing criteria must be taken into consideration when meshing:

- Avoid distorted elements.
- Maintain a good aspect ratio.
- For transitions: use three oriented nodes.
- The percentage of triangular elements in a surface mesh should not exceed 5%.
- The mesh must be as regular as possible taking into account the geometry of the part.
- The size of the elements must be well controlled; the correct elements have a size ranging from 3.2 mm up to 7 mm, with a target average of 5 mm.

The table below summarizes the meshing criteria used:

| Criteria                 | Recommended value | Description |
|--------------------------|-------------------|-------------|
| Size                     | Between 3.7 and 7 (5 is the best) | ![Size](image) |
| Warping                  | h/l<10°           | ![Warping](image) |
| Angle for 4 nodes        | 35°<angle max<135° | ![Angle](image) |
| Angle for 4 nodes        | 30°<Angle min     | ![Angle](image) |
| Aspet Ratio              | 1<Aspect<1,2      | ![Aspet Ratio](image) |

3.3. Data setting

During the data entry part, physical and mechanical properties are assigned to the meshed elements, materials, contacts, stresses and boundary conditions are added. At the end of this step solver input files are generated as output.

www.astesj.com
The challenges of this part are manifested in the assembly of the parts of the model, and the sufficient verification of the model to guarantee a correct first calculation.

3.4. Finite element calculation

After checking and validating the model, the calculation is launched using a solver specific to the chosen scheme and conditions (RADIOSS for the case of vehicle impact) [7].

The solver used solves the equations at each node of the mesh in an approximate way, respecting the fundamental principles of physics, and then assembles the necessary data for post-processing.

The main challenge of this step is to try to reproduce the physical behavior of the structures expected with the numerical approach.

4. Approaches and Methods used in The Simulation

4.1. The Lagrangian formulation

The Lagrangian formulation consists in making a mesh that coincides with the material, this configuration allows visualizing the deformation from the deformation of the mesh element. In structure analysis, we cannot make the Eulerian formulation (which is appropriate to the fluid flow) because we are led to see the behavior of the structure with regard to the displacement of the nodes to illustrate the deformations and which will generate physical phenomena namely the rupture.

4.2. Temporal approximation

The choice of the scheme (explicit or implicit) is made by several criteria: speed, linearity, complexity and cost of calculation... If the problem is dynamic and has non-linear phenomena (such as rupture, damage or buckling...) the explicit approach is recommended.

For static problems with linear behavior (elastic for example), the implicit approach is recommended to have favorable results[8].

The chosen approach depends essentially on the calculation cost that is why the explicit approach is adopted for non-linear dynamic physical problems, especially when a crash simulation is involved. The explicit method is therefore suitable for solving problems of wave propagation or transient fast dynamics. The figure below shows the selection criteria for each of the two schemes:

- Spatial discretization by finite element with reduced integration and a matrix of strip masses.
- A temporal discretization with an explicit schema, with centered differences.

In order to establish the equations of the problem to be solved, it is necessary to calculate certain quantities such as the mass and stiffness of the elements which depend on the geometric domain of the element. The expressions of these quantities are functions of the polynomial type whose degree depends on the approximation chosen at the beginning for the element (linear or quadratic). We have the basic equation (without damping):

\[ [M]\{\ddot{X}_n\} + [K]\{X_n\} = \{\text{Fext}(tn)\} \]

with

- \(M=\) mass matrix.
- \(K=\) stiffness matrix.
- \(X_n=\) displacement at the moment \(tn\).
- \(\text{Fext=}\) resultant of external forces.

Temporal integration by the general form of the Newmark scheme allows to write speed and displacement at time \(t + \Delta t\) according to the same magnitudes at time \(t\), the successive derivations can be approached by a Taylor development using two parameters \(\beta\) for displacement \(x\) and \(\gamma\) for speed \(\dot{x}\)

The passage from step \(n\) to step \(n+1\) is given

\[
\begin{align*}
\dot{x}_{n+1} &= \dot{x}_n + \Delta t \ddot{x}_n + \frac{\Delta t^2}{2} x_n + \Delta t^2 (\beta (\ddot{x}_{n+1} - \ddot{x}_n)) \\
\ddot{x}_{n+1} &= \ddot{x}_n + \Delta t \dot{x}_n + \Delta t (\gamma (\ddot{x}_{n+1} - \ddot{x}_n))
\end{align*}
\]

with: "\(\Delta t\)" is the time step.

Newmark's schema is based on a Taylor development of time functions, this development allows writing the derivative according to the derivatives of the second order and third order up to \(n\)th order according to the precision one wishes to have.

By truncating Taylor's series to the first order, we obtain

\[
\frac{x_{n+1} - x_n}{h} = \dot{x}_n + \varepsilon(h)
\]

The approximation is then of order 1, the truncation error \(\varepsilon(h)\) tends towards 0.

The explicit pattern of centered difference is given for the value pair \(\beta = 0\) and \(\gamma = 1/2\), with these values the method is conditionally stable, the values at the moment \(tn+1\) are calculated from the values at the moment \(tn\).

Figure 2: Status of approaches in relation to types of calculations

The explicit schematic finite element method is particularly well suited to the numerical simulation of crashes and rapid shocks lasting less than a second, they use:

www.astesij.com

Figure 3: The explicit schema of centered difference
In the end, by noting \( U_n \) the displacement, \( \dot{U}_n \) the speed, \( \ddot{U}_n \) the acceleration at instant \( n \), and then the relations are written:

\[
U_{n+1} = U_n + \Delta t \dot{U}_n + \Delta t^2 \left( \frac{1}{2} - \beta \right) \ddot{U}_n + \Delta t^2 \beta \dot{U}_{n+1}
\]

\[
\dot{U}_{n+1} = \dot{U}_n + \Delta t \ddot{U}_n + \Delta t \delta \dot{U}_{n+1}
\]

The values of \( \beta = 0 \) and \( \gamma = 1/2 \) are replaced.

The result is described below:

\[
U_{n+1} = U_n + \Delta t \dot{U}_n + \frac{\Delta t^2}{2} \ddot{U}_n
\]

\[
\dot{U}_{n+1} = \dot{U}_n + \Delta t \ddot{U}_n + \frac{\Delta t}{2} \dddot{U}_{n+1}
\]

4.3. Numerical stability condition

Explicit Schema methods are conditionally stable and should be used with a time step smaller than a limited stability step, calculated from the finite element dimension \( d \) and the sound propagation velocity \( C \) in the material.

\[ dt < dt(\text{limite}) = \frac{lc}{C} \]

\( l_c \): Characteristic element length

\( C = \frac{\sqrt{E}}{\sqrt{\rho}} \): Speed of sound in the material

Avec \( E \): Young’s module

\( \rho \): The density of the material.

This results in:

\[ dt < dt(\text{limite}) = \frac{l_c}{\sqrt{\frac{E}{\rho}}} \]

4.4. Laws of materials

The constitutive law used, in this work, to describe the fast phenomenon (the deformation speed is about 200ms), is the Johnson-Cook law [9].

This hardening law is very widespread. It has been very successfully given its simplicity and the wide availability of parameters for different materials (iron, steel, aluminum, etc.).

The model expresses the stress as a function of the plastic strain, the strain rate and the temperature \( T \):

\[
\sigma = (\sigma_f + b (\dot{\varepsilon}_p)^m (1 + c \ln \left( \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right) \left( 1 - \left( \frac{T-T_{\text{ref}}}{T_{\text{fusion}}-T_{\text{ref}}} \right)^n \right) \right)
\]

- \( \sigma_f \): Elasticity limit
- \( \dot{\varepsilon}_p \): Plastic deformation
- \( \dot{\varepsilon} \): Strain rate
- \( \dot{\varepsilon}_0 \): Initial strain rate.
- \( T_{\text{ref}} \): Reference temperature.
- \( T_{\text{fusion}} \): Material melting temperature.
- \( b \): Work hardening rate.
- \( c \): Coefficient of strain rate.
- \( m \): Exponent of temperature.
- \( n \): Exponent of hardening.

5. The Luggage Crash Test

The test approval standards must be met for a manufacturer to be allowed to market a vehicle. Although, they simply guarantee a "minimum" security, their results are not publicized.

The International Organization for Standardization (ISO) defines, by its standard ISO 27955: 2010 [10], the minimum requirement on the front and rear seats tests as well as partitioning devices, to improve the protection of the occupants of vehicles against the suitcases shifting during a frontal crash.

In this work, we are going to carry out a vehicle homologation study, following the ECE R17 regulation of the United Nations Economic Commission for Europe (CEE-ONU). This study will allow us to verify the resistance of the seats, their anchorages and headrests. It also applies to the design of the rear parts of the backrest and the protection of the occupants against the dangers resulting from the sudden displacement of luggage in the event of a collision [11].

5.1. Crash test scenario

The crash test represents the suitcases crash scenario against the seats during an accident. It consists of loading several suitcases into the boot of a vehicle carrying the seat, the rear floor and the rear part of the passenger compartment. Acceleration is applied to all of the elements, starting from a zero-initial speed. In addition, the law of gravity is applied to the model.

Figure 4 represents the velocity profile applied during the test of crash luggage:

![Speed curve of the crash luggage](speed_law_imposed.png)

Figure 4: Speed curve of the crash luggage

5.2. Suitcases positioning

Among the essential criteria for carrying out this test: the position of the seats and their attachment, the location of the cases
on the rear floor and the acceleration laws. In Figure 3, weakness
the positioning of the suitcases from the seat.

5.3. Simulation of the suitcase crash test

The luggage crash test validates the correct fit of the seats and
their rigidity, and remains one of the most important tests carried
out before marketing the vehicle. Numerical simulation of the test
allows predicting more precisely the real behavior of the crash and
anticipates in advance the optimizations and solutions that are
more expensive in the experimental, either at the structural level or
at the material level [12].

5.4. Criteria

The ECE17 crash test requires several criteria to be met, such as:

- During the test, the test blocks must be retained by the
  backrests and the backrest locking systems must remain
  engaged.
- The backrest frame shall not exceed the plane H-50 mm
  (depending on X vehicle) during the test.
- The headrest reinforcement shall not exceed the plane H-100
  mm (depending on vehicle) during the test.
- Permanent deformation of the backrests, seats, anchorages,
  adjustment systems and displacement systems is permitted
  provided that this does not result in a risk of injury to the
  occupants.
- A white body, containing all the required equipment, shall be
  used for the tests. If head restraints are standard equipment on
  the seats under test, and if they are adjustable, they shall be
  placed in the highest position Figure 4.

5.5. Model data input

It is necessary to define the interfaces between the components:

Type 7 interfaces (in Radioss) to be defined:

- Between the suitcases is the frame of the bench.
- Between the suitcases and the boot carpet
- Between the suitcases and the cash register
- Between the suitcases and the tablecloths of the bench seat

The cubic suitcases are left free, without any restraint or
guidance, so that they can hit the rear seat backrest.

The deceleration curve of the luggage impact performance is
in figure 5.

5.6. Creation of time history and Control and Engine cards

The creation of Time History is done like the ECE14 / R14
service on three main elements:

- The nodes
- The interfaces
- The springs

Each cubic case has a node already entered in the Time History
and useful for post-processing.

The information required to start the calculation and to choose
the outputs is provided in the RADIoss, Engine and Control cards.

- Engine/ANIM/DT (T_START à 0.0025 et T_FREQ à 0.0025)
- Engine/RUN (NUMBER à 1, T_STOP à 0.21)

5.7. Post-treatment and deformation analysis

After the preparation of the model and the start of the
calculation, we move on to the post-processing phase where we
exploit the outputs and analyze the results.

5.7.1. Analysis of the nodal time step

The analysis of the nodal time step allows for each part to check
the addition of mass in percentage % and in grams.

Also, a statistics tablet is available to quickly display parts with
a high mass addition.

Finally, a mass addition report is automatically generated in the
RADIoss file folder of the model to be post-processed.

The verification of the added mass is done in three parts:

The complete model:

- Mass error (at T = 0) < 5%.
- Mass error (final) <10%.

By component:

- Standard parts:
  Added mass < 100% or added mass > 100% and <100g
- Most popular parts
  Added mass < 20% or added mass > 20% and < 20g

Accelerometers:

- Mass added < 100% over the entire simulation, i.e. at the last
  moment.

5.7.2. Analysis of the internal energy curve

The analysis of the total internal energy curve makes it possible
to check the stability of the calculation and to ensure very minimal
deformation of the body and seats after the rise in forces that means
when the forces are maintained.
If the assembly is stable, the calculation can be run over a total time of 0.3s instead of 0.4s. Conversely, it will be interesting to extend the total time and therefore the time of force maintenance, to see if the stability of the body and seats comes later.

5.7.3. Analysis of the deformation

The analysis of the deformation of the seats or bench seat with the environment allows knowing the global behavior of the parts stressed during the calculation. This analysis can be illustrated by a series of videos or photos (front view, top view, and left view, right view) to obtain a complete visual on the progress of the backrests and headrests.

However, it is important that the cubic cases remain behind the files to validate one of the criteria of the R17 service:

Figure 6 shows the numerical simulation at the end of suitcases crash test on the seats:

![Figure 6: Numerical simulation of suitcases crashes](image)

5.9. Local deformation analysis

The material constituting the seat bench is the S500MC grade steel. This structural steel has the mechanical properties showed in Figure 7:

![Figure 7: Behavior law curve of the S500MC](image)

To check for the absence of failure phenomena, simply verify that the relative elongation does not exceed the limit in failure (for example 15% for steel). This is reflected by the plastic deformation. Elongation at break is a dimensionless characteristic of materials. It defines the capacity of a material to deform plastically and to lengthen before breaking. It is written as:

\[ A\% = 100 \times \frac{L_u - L_0}{L_0} \]

- \( L_u \): Ultimate length, or the length just before failure.
- \( L_0 \): Initial length.

Table 3 shows the values of the elongations at break A% of the various components of the model:

| Components          | Steel grade | Elasticity limit \( R_e \) | Tensile strength \( R_m \) | Elongation at break A% |
|---------------------|-------------|-----------------------------|-----------------------------|------------------------|
| Backrest tube       | S500 MC     | 500 (MPa)                   | 550-700 (MPa)               | 12%                    |
| Separability flange | S500 MC     | 500 (MPa)                   | 550-700 (MPa)               | 14%                    |
| central hinge       | S500 MC     | 500 (MPa)                   | 550-700 (MPa)               | 45%                    |

The elongation at break (A%) of the central hinge bracket noticed during the numerical simulation reaches 45% at the upper part of the central hinge bracket, where there is a limit of 21% for the steel grade constituting this hinge.

6. Correlation between experimental and numerical test

The virtual camera can simulate integrated cameras, while image mapping and video synchronization are transformed into easy tasks using integrated tools [13].

Displacement and angle graphs between the entities plotted on the test videos generate useful information that can also be used for correlation with the simulation results.
The correlation between the results of numerical and experimental crash tests is essential to ensure the best level of protection for vehicle occupants. This necessity should therefore leave no room for uncertainty, yet numerical tests sometimes reveal a predictable behavior, often due to the assumptions taken into account during modeling [11].

The developed numerical model reproduces the same behavior as the physical model and this in terms of displacement of the suitcases towards the back of the seats. These displacement values are illustrated in the graphs of the following paragraph.

The parts which represented a very high level of the elongation at break in the numerical test, must be observed in the experimental test in order to check their level of correlation.

6.1. Displacements analysis

In order to validate the numerical model, we compared the displacements of the head restraints and the seats compared to those given by the experimental test, and this according to six points. The correlation result is illustrated in Figure 8 and Figure 9:

![Figure 8: Correlations of headrest displacements](image)

![Figure 9: Correlations of seat back displacements](image)

It should be noted that the difference in correlation between the numerical calculation and the experimental test is less than 10%. This difference can be explained by the existing plays not taken into account in the calculation on one hand, and on the other hand by the quality of the material law in the field of large deformations.

6.2. Deformation analysis

The deformation analysis is performed by correlating the shape of different parts impacted and plastic deformation. We note that the shape of the global bench seat after the impact of the suitcases has remained the same whether in calculation or in the test. Likewise, the central gussets have deformed identically outwardly facing.

Finally, comparing the plastic deformation of the central hinge bracket with that of the real tests, we notice that this deformation is not present.

The Figure 11 shows the difference between the critical strains at break of parts in numerical calculation compared to the experimental one:

![Figure 10: Comparison of deformation of the support of the central hinge](image)

According to the correlation between the two studies, experimental and numerical, we note that we have no break in experimental test on the other hand we noted values of the numerical strains much higher than the breakdown threshold. These stress concentration zones noted are those of the screw fixing zones and the articulation holes.

Functions supporting the center hinge are ensured by means of an axis composed, in reality, of two parts, a plastic part and a rigid steel part. On the other hand, in numerical model, the central axis is simplified to optimize the computation time and it is modeled in a single part and put in a rigid non-deformable body, which does not represent reality.

In order to reach a satisfactory level of correlation, that reflects the experimental reality, an iterative study on the numerical model must be carried out. The solution obtained must be optimal in terms of cost and feasibility.

7. Propositions and Iterations

To meet the modeling requirements and get the best physical results, iterative work is necessary. This work consists in modifying a parameter for each iteration, then analyzing the calculation results. Finally, compare the results of the physical tests with the old basic modeling, in order to have the most optimized numerical solution [14].

The proposed iterations are described in Figure 11.

![Figure 11: Summary of iterations carried out](image)

The results of calculation will be useful for the comparison with the results of plastic strain and behavior of the basic numerical model and with the results of displacement of the real tests [15].
8. Results of The Modification Improvement

8.1. Results proposition 1

8.1.1. Behavior

The behavior of the studied system, for the first iteration, is as follows:

There is a change in behavior from the basic model.

The addition of the two degrees of freedom influences the behavior of the system under study, because the axis has more kinematic freedom.

8.1.2. Plastification

When analyzing the plastic elongation of the studied area of the support of the central hinge, a decrease from 58.1% to 39.05% can be noticed compared to the basic model.

The addition of the two degrees of freedom affects the value of the elongation of the studied area, but this modification is not sufficient to reach a value lower than the limit value of the material of the central hinge support 21%.

8.1.3. Displacement

The measured values are as follows:

- Backrest frame: -156.2 mm at 92.1 ms
- The central headrest: -133.9 mm at 92.5 ms

8.1.4. Analysis of the results

The first iteration aims to quantify the impact of changing degrees of freedom on plastic behavior and deformation.

When analyzing the results of the first iteration, we always notice a value higher than the elongation at break of the studied system which reaches 39.05%, so we still have the numerical break of the central hinge support.

So, although the criterion of not exceeding the measuring planes H-50 for the headrests and H-100 for the seat reinforcement is validated, the modelling used in the first iteration does not meet the objectives set.

8.2. Results proposition 2

8.2.1. Behavior

The second iteration consists of using the geometry of the central axis as it actually is, in addition to freeing itself from the connection with the axis environment by means of the springs, and replacing it with the creation of the interfaces.

The modeling of the second iteration involves changing the behavior of the system under study.

The kinematics of the central axis is no longer linked to the springs as in the basic model and the first iteration, but to the new geometry of the central axis.

8.2.2. Plastification

When analyzing the results of the second iteration, we notice a very important decrease of the maximum elongation value in the studied area from the value 58.1% to 17.2%, this value remains below the limit value of 21%.

In addition to the decrease in elongation, there is a change in the location of the affected zone with respect to the basic model, this zone is far from the end of the hole of the support of the central hinge.

8.2.3. Displacement

The measured values are as follows:

- Backrest frame: -157.1 mm at 92.3 ms
- The central headrest: -132.4 mm at 92.5 ms

8.2.4. Analysis of the results

The second iteration aims at knowing the influence of the use of the real geometry of the central axis on the calculation results.

There is a very significant decrease in the value of the measured elongation is from 58.1% to 17.2%.

The criterion of not exceeding the elongation at break of the material of the central hinge support (21%) is then checked.

Since the criterion of not exceeding the measurement plans H-50 for the headrests and H-100 for the seat reinforcement is likewise validated, the modeling used in the second iteration meets the objectives set, and is adequate for use in future models.

8.3. Results proposition 3

8.3.1. Behavior

For the third iteration, materials specific to the two parts of the central axis were used. The behavior of the studied system is as follows:
8.3.2. **Plasticification**

In the basic model we have a maximum elongation value of 58.1%, whereas the maximum plastic elongation of the studied area reaches the value of 16.85%.

In addition to the decrease in the value of the maximum elongation, we notice a change in the location of the area affected by the plastic elongation.

8.3.3. **Dispersion**

The measured values are as follows:

- Backrest frame: -159.2 mm at 95.5 ms
- The central headrest: -140 mm at 92.2 ms

8.3.4. **Analysis of the results**

Analyzing the results obtained by the modeling used in the third iteration, we notice a significant reduction in the value of the elongation from 58.1% to 16.85%.

Po on has an elongation value lower than the critical breaking value of the material of the central hinge support (21%).

Note that the criterion of not exceeding is checked for the third iteration.

So, the modeling used in this iteration, where the materials of the two parts of the central axis were defined in addition to the creation of the interfaces, meets the requirements set. Therefore, this modeling is adequate for use in future models.

9. **Definition of Selected Modeling Improvements**

The chosen digital model must meet the following criteria:

- Elongation value of the support below the limit value of 21%.
- No modeling complexity
- Adaptation with different simulation models

So, it is quite clear that the model of the first iteration does not meet the criteria for plasticization. We are left with the choice between the second and third modeling.

The modeling used in the third iteration requires a definition of the materials, this definition goes through the supplier's request for materials, in addition to the adaptation of these materials with the materials of the software base, and this is not generic and is only suitable for a well-defined model of the benches provided [9].

On the other hand, the modeling of the second iteration does not require knowledge of the materials, and this simplifies the modeling steps and the instrumentation time, yet the results obtained from the second iteration meet the different criteria set and it is suitable for any bench model since the materials are not defined.

Then the modeling that is the most optimal and that meets all the requirements and objectives is the second modeling with the following characteristics:

- The geometry is defined as it actually is.
- The axis is set into a rigid, dimensionally stable body.
- The material of the shaft is infinitely rigid.
- The interfaces between the axis and its environment are defined.

10. **Conclusion**

The results of numerical simulations obtained show the reliability of finite element modeling in the mesh, complete assembly and data setting. In addition, the iterations performed in numerical modeling on the three aspects namely kinematics (degrees of freedom), geometry and material definition, have a direct influence on the results [16].

This correlation study carried out in this article allowed us, firstly, to validate our numerical simulation of baggage crash and, secondly, to improve the level of prediction of the numerical model of the vehicle intended for other crash tests [17].

This study allowed us to improve the modeling of the rear seat and subsequently reduce the discrepancies between the numerical and physical results [18].

The final numerical model obtained will be used in other crash tests, in particular for homologation calculations such as the ECER14 which ensures the safety of the occupants in the rear seats [19].

**References**

[1] A. Ern, Aide-mémoire - Éléments finis, Paris, 2005.
[2] C. Liu, X. Song, J. Wang, “Simulation Analysis of Car Front Collision Based on LS-DYNA and Hyper Works,” Journal of Transportation Technologies, 4(October), 337–342, 2014, doi:10.4236/jtts.2014.44030.
[3] R. Moradi, G.M. Company, R. Setpally, H.M. Lankarani, “Use of Finite Element Analysis for the Prediction of Driver Fatality Ratio Based on Vehicle Intrusion Ratio in Head-On Collisions,” Applied Mathematics, 4(5A), 56–63, 2013, doi:10.4236/am.2013.45A007.
[4] EUROPEAN NEW CAR ASSESSMENT PROGRAMME ( Euro NCAP ) TEST PROTOCOL – AEB systems, 2015.
[5] V. Singh, S.S. Ahmed, “Automotive Seat Modeling and Simulation for Occupant Safety using Dynamic Sled Testing,” International Journal of Engineering Research and Technology, 3(7), 1501–1505, 2014, doi:10.17577.
[6] U. Nations, I.T. Committee, Adopted technical report on the development of draft Amendment 1 to global technical regulation No. 15 on Worldwide harmonized Light vehicles Test Procedures (WLTP), 2016.
[7] A. Engineering, W. Headquarters, E.B. Beaver, Radiess theory manual-Large Displacement Finite Element Analysis, 0–113, 2012.
[8] Kamila FLIDROVÁ, Contribution à la simulation numérique des crash de véhicules : Prise en compte des non-linéarités matérielles et géométriques, L’ÉCOLE CENTRALE DE LYON, 2010.
[9] R. De Cássia, P.G.M. Flávio, A.B. de S. Oliveira, “Assessing the crashworthiness of a vehicle seat for rear and frontal impacts,” 16(1), 1–19, 2019, doi:https://doi.org/10.1590/1679-7825262.
[10] ISO/TC 22/SC 36 Safety and impact testing. Road vehicles — Securing of cargo in passenger cars , station wagons and multi- purpose vehicles — Requirements and test methods, 2010.
[11] R. Vroman, P. Gloyons, J. Roberts, Testing of Rear Seat Strength in Cars, 2003.
[12] D.S. Dima, D. Covaciu, “VEHICLES FRONTAL IMPACT ANALYSIS USING COMPUTER SIMULATION AND CRASH TEST,” International Journal of Automotive Technology, 20(4), 655–661, 2019, doi:10.1007/s12239.019-0062-3.
[13] I. Skozrit, J. Fran, Z. Tonkovi, M. Surjak, L. Krstulovi, “Validation of numerical model by means of digital image correlation and thermography,” 101, 450–458, 2015, doi:10.1016/j.proeng.2015.02.054.
[14] H. Chen, H. Chen, L. Wang, “Analysis of Vehicle Seat and Research on Structure Optimization in Front and Rear Impact,” World Journal of
[15] P.M. Dixit, U.S. Dixit, Plasticity: Fundamentals and Applications 1st Edition, Kindle Edition, 1st Edition, 2014.

[16] P. Kangralkar, G. Chidambaram, K. Hendre, “Study of Cargo Barrier in ECE 17 test (Luggage Retention) Regulation,” in 2015 India Altair Technology Conference, 1–8, 2015, doi:https://doi.org/10.4271/2002-01-1041.

[17] D.W. Shin, N.H. Kim, S.S. Lee, S.B. Hong, “Development of Seating System with GMT for ECE 17.07 (Luggage Retention) Regulation 2002-01-1041,” SAE 2002 World Congress & Exhibition, 07, 9, 2002, doi:https://doi.org/10.4271/2002-01-1041.

[18] R. Likhonina, NUMERICAL SIMULATION OF IMPACT WITH BARRIERS, CESKE VYSOKE UCENI TECHNICKE V PRAZE, 2015.

[19] D. Vangia, F. Begania, F. Spitzhüttl, M.-S. Gulinon, “Vehicle accident reconstruction by a reduced order impact model,” Forensic Science International, 298, 2019, doi:10.1016/j.forsciint.2019.02.042.