ELASTIC-PLASTIC BEHAVIOR OF A GT CAR SEAT RECLINER – NUMERICAL MODELING AND EXPERIMENTAL TESTING

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ABSTRACT

The numerical modeling and the experimental testing are two key methods used in the design engineering field. The integration of two approaches in the design process allows the validation of new models for existing components, due to their complementary features for the process itself. Such process is performed on an element of a seat for a Gran Turismo sports car.

In this thesis, after an early crash test of a rear collision, an improved numerical model for a structural component (recliner) of the seat is created. Thus a validation process is performed by a generic comparison between the results of simulations and experimental traction and rupture tests. Finally, a simulation of a collision test is performed by the integration of results obtained from numerical models with the multibody model.

The analysis mainly focused on, but not limited to the seat recliners; knowing that the obtained results will be a path for the realization of an advanced design. In other words, the analysis of the recliner and the obtained results will give a deeper knowledge about the component’s behavior, allowing to use this information to achieve a better design.

Keywords: seat recliner, simulation, FEM, rear collision, model validation
La modellazione numerica e i test di verifica sperimentale sono i due metodi principali utilizzati nel campo della progettazione meccanica. L’integrazione dei due approcci nel processo di progettazione permette di validare nuovi modelli per i componenti esistenti. Tale metodologia è quindi stata utilizzata su di un elemento di un sedile per autovettura di tipo Gran Turismo.

Questa tesi si sofferma sulla definizione di nuovi modelli numerici per un componente strutturale del sedile che prende il nome di recliner. Dalla comparazione tra i risultati delle simulazioni e i dati ricavati da test sperimentali di trazione sul recliner stesso e rottura del sedile è quindi stato possibile eseguire un processo di validazione dei modelli ottenuti. In conclusione, dall’integrazione dei risultati numerici ottenuti con un modello multibody è stata definita una simulazione per il test di collisione posteriore eseguito sull’intero sedile.

L’analisi è quindi stata principalmente concentrata sul recliner del sedile per poter ottenere modelli dell’elemento stesso utilizzabili nel processo di progettazione. In questo modo è stato possibile il raggiungimento di una conoscenza approfondita del comportamento del componente permettendo così di utilizzare queste informazioni per una migliore progettazione.

Parole chiave: supporto schienale, simulazione, FEM, impatto posteriore, validazione del modello
CHAPTER 1

INTRODUCTION

Safety of drivers is one of the most crucial factors needed to be improved in the recent years, mainly starting from the motorsports. Diverse technological improvements have been made in all parts of the vehicles, although in terms of safety, they were mainly focused on the design of the interior, where the user interaction is the most. Considerable improvements in designs have steadily reduced injury and death rates in all first world countries. Nevertheless, primary cause of injury-related deaths are still related to car accidents. [1]

The attention in this sense, regarding safety of the driver is given to dissipate the kinetic energy of the body and decrease deceleration. The effects of the front and side impacts are almost always prevented thanks to the presence of the seatbelts and the airbags. However, the problem lays down that there are still lack of deep measures regarding the rear collisions. The protection feature of the seatbelt or the airbag are generally diminished when there is a rear impact. What is more, there might occur a problem specific to the cars including four seats, where the safety of passengers seated in the back might be compromised due to possible high deformations of the backrests. Hence the studies regarding the rear collisions require the attention on the design improvements of the seat and its components.

This thesis explains about the elastic-plastic behavior of a seat component for a Gran Turismo car. The component is a structural part of the seat that allows to fix the
backrest carbon shell to the base carbon shell, which is called a seat recliner (fig. 2.2.B-1). For understanding its behavior during a rear collision, a method is applied for numerical modeling and the validation is performed by comparison with experimental testing.

Figure 1-1. Car seat shown as the real [III] and the 3D computer model.

This method is necessary to be performed because during the rear crash test of the seat, it had been observed that there was an excessive deformation due to lack of properties of the recliner. Having this problem, the attention should be given to arrive a redesign of the component. For this reason, new numerical models were required to be developed and refined by comparing with experimental tests.

Mainly two kinds of models were defined. Initially, a first series of FEM models were created for analysis. Further a second model was issued considering a Simmechanics multibody system that was integrated with the results obtained from the first model.

For the numerical approach as mentioned, it was possible to use Finite Element Method (FEM) to create the models. By the use of FEM, it is possible to have a detailed
evaluation of where structure bends or twists, and shows the distribution of stresses and displacements. This powerful tool can also help the construction, refinement and the optimization of the entire design phase of the complex mechanical systems. In this way, FEM is able to respond to the need in the design process in many applications. [III]

In the end, the numerical models created by this tool, also being done the validation, could be used to redesign and to optimize the recliner, or the seat multibody.

In the next chapters, both experimental and numerical approaches for the analysis and design of the seat recliner are described.

In Chapter 2; a brief description of the seat recliner is given. The steps required to perform the initial experimental tests are described into details. These tests are rear collision crash test, traction tests of the seat recliner and a rupture test of the full seat.

In Chapter 3, the preparation of the models for FEM analysis is described, mainly for the traction tests and for the rupture test. The main configurations; like the materials, boundary conditions and mesh properties are described for the models.

In the next chapter, the validation of the tests is demonstrated by the comparison of simulation and experimental tests’ results. For the purpose of more realistic behavior and more similar (overlapping) results of the curves between two approaches, the steps of the traction tests with an arm is refined. Also a description is made for a double cycle model, which allowed to have more realistic behavior of this test. The steps and the results are explained in detail. Finally, the post-processing and the comparison of the results for the rupture test are mentioned in the end of Chapter 4.

Up to this point, the validation of the simulation model is performed by means of the comparisons between the two approaches of different tests. From this point, the simulation model that was improved by the previous tests is also used for the computation of the torque-angle characteristics. In Chapter 5, the characteristics of previous simulations are compared with the result of the models realized in this work.
The main differences in terms of materials, boundary conditions etc. are described. The improvements are shown by the comparison of the results of the different models.

Eventually in Chapter 6; the multibody simulation and the integration of the model with the recliner’s torque-angle results is explained. Comparison of the results between multibody simulation and crash test were also reported.
CHAPTER 2

EXPERIMENTAL TESTS

1 – CRASH TEST OF A REAR COLLISION

In the experimental base, a case of an accident was performed to show the effect of a rear impact. An environment, including a dummy, seated and buckled to the seat, was prepared and set on a platform. The platform was able to give the effect of a rear impact, typically seen in rear crash accidents. The impact was applied to the seat and the performed test results were evaluated.

Figure 2.1-1. Seat Deformation Phase during Rear Impact Experimental Test on the Seat & the Dummy.
The same values of the experimental test were also applied to the simulation models; from an assumed weight of 65 kg, the impact force is calculated as 20000N (65kg x 30 x 9.8 m/s² = ~20kN) from a point of the backrest that is about in the middle section (0.45xHeight of the backrest). [IV]

Considering the load effect is divided equally among the right and left recliners, the force applied to one of the recliners has been defined as 10 kN.

The height of the backrest is defined from the H point, or hip point that is defined by the standards. [V] According to the definition, the H-point is described as a theoretical location of the occupant’s hip, to specify the pivot center point between the upper legs and the torso and it is used for defining and measuring vehicle seating properties, such as seating comfort, visibility from the vehicle into traffic and other design factors. Technically, the measures of a 50th percentile male occupant is taken as a base computation for the H point. [VI]
For the analysis to be performed, the height of the arm to apply the load to be applied is defined with respect to the total height of the backrest.

According to the configuration the arm length \( h \) can be computed as follows:

\[
h = \left( b \cdot \frac{a}{b} \right) - (H - c)
\]
where ‘b’ is the total length of backrest and ‘a’ is the defined height of the arm with respect to ‘H’, which is the hip point, and ‘c’ is the length of the recliner with respect to ground normality.

\[ a = 0.45 \times b \]

As soon as the crash test had been performed, a high deformation of the seat was realized. This high distortion in a high deceleration rate specifically referred to its recliners (fig. 2.1-5).

Figure 2.1-5. The deformed form of the right recliner after the crash test.

Therefore an in depth analysis to understand the recliner’s behavior was necessary in order to solve this problem. Further experimental and numerical tests were applied specifically to the recliners.
2 – THE TRACTION TEST

During the rear crash, the analyzed component; the seat recliner, has the function to have a plastic deformation in order to dissipate the energy and decrease the body deceleration and thus the applied forces. To have more sophisticated understanding of this behavior, one of the tests that was applied to this component was the traction test.

A – REASON OF THE TRACTION TEST

The main objective of the traction test was to obtain the validation of the simulation model of the recliner by performing and comparing the experimental traction test results with a simulation result using ABAQUS® standard software. When the real test and the simulation results converged, it was possible to continue with other complementary tests of the recliners (traction test with arm, rupture tests etc.). As a conclusion of the consecutive test results, along with the traction tests, the obtained simulation results would be able to perform other tests; for instance, a complete multibody simulation, which is explained in later chapters.
B – STEPS OF THE PROCESS

1 – Preparation of the Traction Test

In the initial phase, preparation of the traction test specimens were performed by marking the left & right recliners, as well as the rigid connection parts for the purpose of measuring the displacement change after the test from the videos. The obtained information provided the comparison and modification between the experimental and simulation test results.

All three tests were recorded by two cameras, with two views of the specimens, the front and the bottom views, so that the displacement after the tests were able to be calculated from one video and controlled by another one.

Figure 2.2.B.1-1. Seat Recliner Marked for Video Analysis.
Figure 2.2.B.1-2. Upper Traction Element with the 3D CAD Model with Dimensions.

Figure 2.2.B.1-3. Lower Traction Element with the 3D CAD Model with Dimensions.
2 – Material Characteristics of FE-E420

The characteristics of the recliner material UNI 5867 Fe-E420 is shown below as the chemical composition in table 2.2.B.2-1 and the mechanical properties in table 2.2.B.2-2 are given, respectively. [VIII]

<table>
<thead>
<tr>
<th>Chemical elements:</th>
<th>C max</th>
<th>Si max</th>
<th>Mn max</th>
<th>P max</th>
<th>S max</th>
<th>Cu max</th>
<th>Cr max</th>
<th>Ni max</th>
<th>V max</th>
<th>Nb max</th>
<th>Al min</th>
</tr>
</thead>
<tbody>
<tr>
<td>% by mass:</td>
<td>0.20</td>
<td>0.60</td>
<td>1.00</td>
<td>0.030</td>
<td>0.025</td>
<td>0.55</td>
<td>0.30</td>
<td>0.50</td>
<td>0.12</td>
<td>0.05</td>
<td>0.02</td>
</tr>
</tbody>
</table>

**Table 2.2.B.2-1. Fe-E420 Steel Chemical Composition -% by Mass.**

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Yield Strength [N/mm²]</th>
<th>Tensile Strength [N/mm²]</th>
<th>Fracture Elongation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>t ≤ 16 mm</td>
<td>420</td>
<td>400</td>
<td>19</td>
</tr>
<tr>
<td>t &gt;16 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t &lt; 3 mm</td>
<td></td>
<td>520-680</td>
<td>19</td>
</tr>
<tr>
<td>t ≥ 3 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2.2.B.2-2. Fe-E420 Steel Mechanical Properties.**

With respect to these properties of Fe-E420 steel, yield stress and the ultimate tensile strength values were based on the values given in Table 2.2.B.2-3.
<table>
<thead>
<tr>
<th>Materiale</th>
<th>Modulo Elastico [GPa]</th>
<th>$\sigma_{snervamento}$ [MPa]</th>
<th>$\sigma_{rottura}$ [MPa]</th>
<th>Deformazione plastica a rottura</th>
<th>True Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe-E 420</td>
<td>206</td>
<td>420.9</td>
<td>576.0</td>
<td></td>
<td>0.1795</td>
</tr>
<tr>
<td>Fe-E 380</td>
<td>206</td>
<td>308.7</td>
<td>544.5</td>
<td></td>
<td>0.1880</td>
</tr>
<tr>
<td>Fe-E 340</td>
<td>206</td>
<td>340.6</td>
<td>504.3</td>
<td></td>
<td>0.2046</td>
</tr>
</tbody>
</table>

Table 2.2.B.2-3. Fe-E420 Steel Yield and the Ultimate Tensile Stress values along with True Strain.

3 – The Experimental Test

Right after the initial simulation results (which is described in Chapter 3), the traction test was performed with three tests; firstly with the left recliner, then with the right recliner, and finally again with the right recliner by tilting of the upper traction element in order to have an application of a torque. As a result of the first two tests, the traction of the right and the left recliner configurations, it had been realized that the preliminary simulation results didn’t match with the experimental results, which had an upper load limit of around 22kN. During the tests, the application of the load increment preserved linear with time.
Figure 2.2.C.3-1. Left Traction Test Specimens with Front and Side Views.

Figure 2.2.C.3-2. Right Traction Test Specimens with Front and Side Views.
Figure 2.2.C.3-3. Right Traction Test Specimens with Arm with Front and Side Views.
3 – REALIZATION OF THE RUPTURE TEST

Significance and the use of the rupture tests points out that these testing methods are performed generally for the realization of the ultimate load-carrying ability of the specimen through the deformation process. [IX]

From the point of view to the seat characteristics, the test was applied with respect to reflecting the resulting rupture effects of the rear crash on the seat multibody. In this sense, an experimental system had been established for the test, and the results that were obtained from the sensors and the videos, which were recorded during the test, were to be compared with a simulation model results.

A – EXPERIMENTAL PREPARATION OF THE TEST

Through the configuration and the realization of the experimental test, an environment was created in order to pull the seat until the rupture occurred. Therefore, the seat was fixed vertical to the ground and tied to a small bridge crane with a thick, rigid rope from a certain point to give an arm during pulling. Furthermore, sensors were used to measure force and rotation values during the test, and also some regions of the seat were marked for the use of computations from videos.
After the values were obtained, the torque was computed from the force multiplication with the arm.

\[ \vec{T}_e = \vec{F}_e \times \vec{R}_e \]

where \( \vec{T}_e \) indicates the torque and \( \vec{F}_e \) and \( \vec{R}_e \) indicate the force and the arm vectors of the experimental test, respectively.

For the calculation of the arm dimension, the frames that were captured from the videos were used to obtain the values changing during testing time by applying a pulling. With the computation of the force component, which is normal to the arm, the torque was able to be obtained.
Figure 2.3.A-2. Rotation of the Backrest as the Arm during the Test.

In terms of the simulation results computation a similar way of computation was also applied to obtain consequent torque-angle plots.
CHAPTER 3

THE SIMULATION MODELS FOR FEM ANALYSIS

1 – MODELS PREPARATION FOR THE TRACTION TEST

A – PRELIMINARY SIMULATIONS

Prior to the implementation of the traction test, preliminary analysis were performed with a load range mainly from 5 kN to 10kN to acquire the required stress results. It was assumed the part wouldn’t stand more than 10 kN load.

For this analysis, the exact same configuration of the experimental tests were made using ABAQUS® Standard Software with the same dimensions and same type of connections.
Figure 3.1.A-1. Result of a Preliminary Simulation; Mesh size: 2.8 mm, load: 6750 N.

For the objective of more accurate results, some modifications like changing the mesh size and mesh type (Quad-dominant, Tri) and linearity type (Linear or Quadratic) were performed.

Figure 3.1.A-2. Result of a Preliminary Simulation; Mesh size: 2.8 mm, load: 6000 N.
Later on the usage of displacement, instead of force and connection types were changed.

**B – THE SIMULATION MODEL FOR THE TEST**

The main objective of the simulation was to obtain confirmed results similar to the experimental results. For this purpose, the model was created with the exact configuration in a way to have the same type of constraints, interactions, material properties and loads. This model was created in ABAQUS® Standard Software as a shell component with a thickness of 3.1 mm (obtained by checking with the caliber), by importing the 3D CAD model.

Apart from using upper and lower element models, instead the points where the constraints attached were defined and the connection of the recliner to the elements were specified as two couplings to the surfaces where they connected to each other. Instead in the case of the last test with the right recliner as an arm, the coupling of the upper part in the simulation was specified as a coupling between the reference point and three bolted joint holes. Elastic and plastic behavior of the material was used same given as the Fe-E420 steel properties.

Two boundary conditions were assigned from the constraint reference points; as for the lower constraint, it was assigned as three displacement constraints from the relative reference system axis (U1, U2 and U3) and a rotation constraint around X axis (UR1). Contrarily for the upper constraint, two displacement constraints (U2 and U3) were defined and a displacement value was defined for the X axis (U1) in order to simulate the traction.

The meshing of the simulation was performed with quad-dominant element type with a 4 node linear geometric order. Initial tests were performed with bigger mesh dimensions, and later it was modified around 2.5-3 millimeters.
The configuration for step and mesh size were two main factors for the modification of the model and obtaining the final results. In the step section, the total number of 1000 increments was generally held, and total time of the simulation was the same based on the real testing times. Initial increment time is defined as 1 or 2 seconds, the minimum and the maximum time increments were kept as default.

Figure 3.1.B-1. Configuration of the Simulation Model of the Right Recliner with the Couplings, Mesh and Reference Points.
2 – RUPTURE ANALYSIS PREPARATION & THE SIMULATION MODEL

Successively, the realization of the rupture test with respect to numerical analysis was followed, owing to validate and to establish a complete multibody simulation model. In this regard, a simpler model was prepared for the realization of a rupture test so as to obtain results similar to experiment.

Hence like the experiment configuration, an interaction was created approximate to the linking rope property was created between two points, where on one side the displacement was adjusted, and on the other side the arm was connected.

![Figure 3.2-1. The Rope Connection Embodiment of the Simulation Model.](image)
The height of the arm was measured from the real seat and assigned to the simulation model. Additionally for the model’s preparation, Fe-E 420 material properties were used and the boundary conditions were defined. The interaction properties were made in the same way that had been established in the seat multibody. For the interactions of the upper part, surfaces in the model were defined as nodal points, like the bolt joint holes (fig. 3.2-2).

![Figure 3.2-2. Bolt Holes Interactions' Configuration for the Shell Model.](image)

In terms of the boundary conditions, there were 4 main components that were defined to give identical effects as compared to the real part connections. In general, one of them was aimed to sustain and to enable the main contact between the backrest and the lower seat, and the other three portions were basically established to contribute the stability of the recliner inside the seat multibody.

To perform the test, the arm was defined by coupling the upper part, where the 6 bolt joint holes and a bigger hole available at the center. All these holes were coupled to
the arm which connected to a center point where the load to be applied was mainly concentrated.

To enable the full representation of the experimental test behavior, other three conditions were also described in the model. First of all, the bottom of the recliner was fully constrained (fig. 3.2-3). Although when the connections are checked in the real seat, or in the computer seat model, it can be realized that the constraints don’t match completely in the same way with the simulation models. However, by taking into consideration the type of the test, it is recognized that the correct way of representation of the bottom constraints should be applied in a way that was performed in the models, where the closest behavior of the real experimental tests could be obtained. So that the effect of the surrounding components of the seat on the recliner during the test could be demonstrated.

![Figure 3.2-3. Boundary Conditions of the Bottom Section of the Shell Model.](image)
The other two constraints were generated in the same way that were defined in the seat multibody. A small arm that is mounted between an inner cylindrical component and the lower seat (fig. 3.2-4) is also implemented in the simulation as an interaction connection between a reference point and the hole’s section in the lower part of the recliner.

Similarly, another bolt joint that is connecting the recliner to the backrest from a rear section is implemented in the model. It was described in the simulation model as a restriction of two boundary conditions around the bolt hole (fig. 3.2-5).

Figure 3.2-4. 3D Solid Multibody Model Showing the Small Arm to the Lower Recliner Holes and Back Region to Backrest Connections.
The arm was arranged not exactly perpendicular to the mounted bottom surface, but a slope of 22.5 degrees was defined, hence the model was in accordance with the actual seat configuration, in which the backrest is mounted with the same slope.

Apart from the material properties and the boundary conditions, a third factor had to be optimized regarding the simulation model; the mesh properties. The mesh element type and the mesh size that was utilized in the model was examined with several tests for the optimization and the choice of the correct type and size which enabled a less time consumption and issued more similar plots with the experimental results.

For the shell model preparation, the type of mesh that was used had a quadratic shape which had the properties of a linear element type with a 4 node algorithm. For the geometric order, also a quadratic element with an 8 node algorithm was also experienced, but there wasn’t an effect of changing results, therefore the linear geometric order was performed due to time saving purposes.
CHAPTER 4

VALIDATION OF THE SIMULATION MODELS & COMPARISON OF THE RESULTS

1 – TRACTION TESTS’ RESULTS

In this chapter, obtained results are shown considering the traction tests’ simulations and all the followed steps are specifically explained in order to have the validation of the defined models.

Considering the quality of the results of the analysis there is the need to improve some of the models by refinement process because the behavior of the recliner itself was not able to be performed directly as it was represented in the real test.

A – COMPARISON OF RESULTS FOR THE EXPERIMENTAL AND NUMERICAL APPROACH

When the results were compared with the defined configuration, initially there was a problem occurred, which was a mismatch between the output of the simulations and the experimental tests. Two main different configurations below were the base of the
simulation phase where the second of which was concluded with the solution of the problem and with more similar results:

1- Simulation with a displacement where the test data was used: The simulation in this first case was performed by considering the final displacement value that is taken from the real test results. Although with the help of some configuration, like changing the mesh size or specifying and increasing the damping factor in step section, more convenient results were able to be obtained, it was not close enough to the experimental ones.

![Graph of Left Recliner Simulation](image1)
![Graph of Right Recliner Simulation](image2)

**Figure 4.1.A-1.** Comparison between the Simulation and Experimental test Results of Left and Right Recliners.
2- Simulation with a displacement that is defined from the experimental traction test videos: In this case on the other hand, the stiffness of the traction test machine was taken into account, making the true displacement value lower than the real test results, due to the bending of the upper part of the machine. Therefore, the total displacement became the sum of displacements due to the recliner and due to the bending of the upper part.

\[ \Delta l_{\text{total}} = \Delta l_{\text{bracket}} + \Delta l_{\text{machine}} \]

The solution to this problem was found by the calculation of the displacement values of the specimens from the videos that were recorded during the test. With the use of a MATLAB® software, the videos were clipped, having the unnecessary parts cut out, and in the next step the relevant test times, typically the initiation and the ending of the test, were saved as photo frames. Consequently two points, which allow the total deformation of only the recliner, neither the other components, nor the testing machine, were chosen as same for each frame. After that, the number of pixels between these two points was measured by considering only the main traction axis for both frames and the number of pixels that referred to the computed elongation. Comparing the initial ratio between the actual distance (in millimeters) and the measured pixels, the millimeter/pixel ratio is obtained, which is then used for the calculation of the final elongation in millimeters (\(\Delta l_{\text{bracket}}\)). These values of elongation for the left, right and the right with arm were used as traction displacements for the simulation models, instead of the ones from the measurements of the experiment.

As a result of this second configuration, the computation results that were obtained from the simulations became as close as the dynamometer experiment results. Except from the small changes in some regions, it was likely to get correct slopes and final stress and force values.
Figure 4.1.A-2. Comparison between the Simulation and Experimental test Results of Left and Right Recliners with a New Elongation.
Figure 4.1.A-3. Comparison between the Simulation and Experimental Test Results of the Right Recliner with Refinement and a New Elongation.

Figure 4.1.A-4 Comparison between the Simulation and Experimental Test Results of the Right Recliner Test with Arm with a New Elongation.
Figure 4.1.A-5. Deformed Models of the Left and Right Recliners.
B – REFINEMENT FOR THE SIMULATION TEST OF THE RIGHT RECLINER WITH ARM

As though the results of the last simulation were close to compared experimental results, there was a problem of the range that; when the behavior of the recliner changed from elastic to plastic and when the test started to become as traction than bending of the recliner, there appeared a deformation of the bolt holes. This behavior of the recliner was not able to be performed directly as it was represented in the real test, however a similar behavior could be performed by a small contribution in between the test. This contribution was the addition of a spring to the system configuration, so that for a certain period of the test, the spring was able to give a simulation of a lower force due to the plastic deformation of the holes and giving closer results to the obtained experimental results.
Different configurations of the spring to the system were made to get the most similar results; hence the following steps were applied for the final configuration:

1 – For the spring contribution in the middle range, the total process is divided into three sub-processes, first part with mainly elastic field, second part with the spring, and the third part that is the resting deformation of the recliner. The configuration was made in order to enable the spring to be active only in the second region, and not in the first and third regions, so the test results were not to be affected.

2 – Initially for the first deformed region, the necessary load was defined without the contribution of the spring and the simulation was aimed to perform until the second region.

3 – As soon as the test reached to the second region, another step was defined for the spring, for which no effect to the elastic recovery of the recliner and only the lower force effect was aimed to be obtained. This type of attitude was provided by restraining the system deformation with a boundary condition, and having the spring connected to the point, applying a displacement -which is a subtraction of the second elongation value from the initial elongation- in the opposite direction of traction to pull the spring, there appeared the result of the aimed lower force increase in the second region in the end.
Figure 4.1.B-1. 3-Steps Configuration Showing the Applied Main Forces for Each Step and the Movement of the Deformed Spring.

4 – Finally in the third region, the rest of the load was applied to keep the test going till the end, while also to keep the spring in the final still condition; the opposite pulling point was kept to move in the same configuration with another displacement boundary condition.
Figure 4.1.B-2. Comparison between the New Simulation and Experimental Test Results of the Right Recliner with an Arm with New Defined Elongation.
Figure 4.1.B-3. Plasticization of the Recliner in Different Regions (Due to the refinement of the material in order to consider that the test is done with the recliner already plastically deformed).
2 – IMPROVEMENTS OF SIMULATION MODEL

CONSIDERING DOUBLE CYCLE TEST

The improvements for all the type of test models were necessary to be followed during the process of the project. However, more discrete, in depth setting configurations were necessary on a specific simulation model, that was for the right seat recliner, which the test followed with an arm. The simulation that was defined for the right recliner with arm was able to give the results that, even if they are close to experimental test results, they were obtained using a setting of the test that can be improved. By this refinement, better results were able to be reached.

Considering the real test, the component that was submitted to traction with arm is the same that had been used for the simple traction test. This means that the element itself had been already plastically deformed and it sustained some residual stresses. These things led to have a change of the mechanical properties and so the behavior became different with respect to the hypothetical test done starting with the undeformed recliner.

Hence new simulation models were created in order to enhance the computation results. These tests were based on a double cycle to consider the effect of a change in the mechanical properties, which had already changed after the initial traction test. In other words, the configuration allowed to have the integration of initial traction test results with the traction test with an arm, which aimed to be analyzed.

With this new simulation approach, more desired results could be obtained, however some problems related to the settings of the simulation model had to be fixed. These settings, or refinements were done by steps of improvements described in the next chapters.
The first configuration of the double cycle test was the one based on the double coupling. It means that it was performed to define all reference points to have the couplings for the simple traction and the traction with the arm of the recliner.

**Figure 4.2.A-1.** First Test Configuration (simulation with double coupling).

**Figure 4.2.A-2.** Magnified Top Region Showing the Reference Points for the Couplings Configuration from the Initial Test.
The displacements and the boundary conditions applied at the reference points are defined in order to have the simulation of the two tests. Looking at fig. 4.1-2, it can be realized that the point on the left is the one for the traction test and the points in the upper part are the ones used for the simulation of the second test.

Though with this configuration, a problem occurred that the imposed displacement to have the simulation of the first test changed the position of the reference points for the second test. Having no information about the new location of these points it was not possible to apply the right displacement values in the other steps. This is due to the configuration of the simulation software ‘ABAQUS®’, about the definition of the dislocation. This imposed to apply the displacement having a reference of the position for the starting points that were defined before running the simulation.

Eventually, some results appeared to be different from the experimental test results were obtained, which can be seen in fig. 4.2.A-3.

![Double cycle test with double coupling](image)

**Figure 4.2.A-3. Results of the Simulation with Double Coupling.**
Having this problem proved that it was necessary to search for other settings for the tests in order to improve the results quality.

**B – DOUBLE CYCLE TEST WITH THE DEFORMED GEOMETRY**

The second configuration of the double cycle test was the one based on imported geometry, which was deformed, and residual stresses that were obtained by the simple traction test. In this way the simulation could be defined considering only the second test using the deformed recliner obtained by the first test.

To import the deformed shape, initially the traction test simulation was performed and the final result was exported as the recliner geometry for the second cycle. The obtained part was deformed orphan mesh without the shape, so that for the part to be used by the simulation software, a 3D modelling program, ‘CATIA®’, was used to convert the orphan mesh and obtain an appropriate geometry. Having this part, it could now be imported and base on this the elements definition (reference points, local reference systems ...) for the simulation.

The deformed geometry of the recliner obtained by the initial traction test is shown in fig. 4.2.B-1.

![Recliner Deformed Geometry Obtained by Traction Test Simulation](image)

**Figure 4.2.B-1.** Recliner Deformed Geometry Obtained by Traction Test Simulation.
To increase the quality of the analysis also the import of the state of residual stress values was required that were sustained on the recliner after the first test. These stresses were generated by the plastic deformation of the component itself and allowed to consider its change of mechanical properties leading to a better quality of the results obtained by the simulation. To import the residual stresses, the job result file of the simple traction test was considered and by using a command (Predefined Field), which precedes in the Load Module of the program, the values were able to be loaded. [X]

Figure 4.2.B-2. Second test configuration (simulation with deformed geometry).

For this setting of the simulation, only the reference points were considered for the coupling that allowed to have the arm.
The displacements and the boundary conditions applied at these reference points are defined in order to have the reproduction of the only traction test with arm.

Two problems, which did not allow to obtain reasonable results mainly occurred with this type of configuration:

1- The first one was related to the mesh of the imported deformed geometry because it was of a not good type and of a fixed dimension without the possibility of change. This was due to the restriction of the 3D converter software that allowed to obtain an appropriate geometry starting from the deformed mesh. With this step the mesh itself was changed from one mode based on the quadratic shape to another one based on the triangular shape of fixed dimension. This change decreased the quality of the results that were obtained by the computation (fig. 4.2.B-4).
2- The second one was related to the development of the constrained reactions on the reference points due to the application of the predefined field of stresses on the recliner. These forces generated an increase of the force applied to deform the recliner leading to inaccurate results of the simulation. In any case these stress conditions on the component was necessary to consider the change of mechanical properties of the component due to the plastic deformation that had appeared on the recliner itself after the initial traction test.

The results from the initial tests with wrong definitions were obtained initially and can be seen in fig. 4.2.B-5 for comparison.
Having these problems a new way of refinement in order to improve the results quality became necessary. This refinement is done solving the two problems explained before:

1- To fix the issue related at the use of the deformed geometry it was a compulsory to use directly the undeformed geometry. Hence there was a lack of shape refinement for the component although the problems due to the import of the previous part of the recliner were avoided.

2- To solve the problem related at the constraints reactions some release steps needed to be applied before the computation steps, which allowed to have the discharge of these forces. These reactions were developed due to the application of the predefined field of stresses and by applying these steps, the problem in this matter was ceased. With the use of the stresses, a clear improvement on the results was observed.

**Figure 4.2.B-5. Results of the Simulation with a Deformed Geometry.**
C – REFINEMENT OF DOUBLE CYCLE WITH RELEASE STEPS

The third configuration of the double cycle test was the one based on the application of the release steps, that allowed to have discharging of the constrained reactions, and the use of the initial undeformed geometry. In this way the simulation could be defined considering only the second test using the residual stresses obtained by the first test and solving the problems that were encountered with the second simulation configuration.

To use this setting there was an addition, before the application of the traction load, of two discharge steps for the second test and one, after the application of the load, in the simple traction test that was done to obtain the residual stresses. To define these steps in the simulation software (ABAQUS®), another command; ‘Create Step’ that is present in the ‘Module Step’ was utilized. [XI]

In the first test the release step was obtained by considering the boundary conditions, which were defined exactly as in the traction phase, but without the applied displacement used to generate the force. This allowed to have a state of residual stresses without the influence of the constrained reactions.
Figure 4.2.C-1. Definition of a Release Step for the Initial Traction Test.

Considering the second test; two discharge steps were defined in the following ways:

1- The first one was obtained as the boundary conditions; the locking for the base reference point and the fixing of the displacements on ‘y’ and ‘z’ axis for the reference point of the spring and the system without the applied displacement used to generate the force (fig. 4.2.C-2).
2- The second one was having the boundary conditions defined as a restriction for three displacements along the reference system axis and the rotation around ‘x’ axis for the base reference point, the fixing of ‘y’ and ‘z’ axis displacements for the upper reference point and the fixing of ‘y’ and ‘z’ axis displacements for the reference point of the spring. This configuration of locking was the same that had been used in the complete traction test with the arm and the system, as before, was defined without the applied displacement used to generate the force (fig. 4.2.C-3).
**Figure 4.2.C-3.** Definition of the Second Release Step for the Traction Test with Arm.

The configuration for the double cycle test with release steps is shown in fig. 4.2.C-4.

**Figure 4.2.C-4.** Configuration of the Third Test (simulation with release steps).
For this setting of the simulation only the reference points were considered for the coupling that allowed to have the arm (fig. 4.2.C-5).

*Figure 4.2.C-5. Configuration of the Third Test with a Magnified Region showing the Reference Points for the Coupling.*

The displacements and the boundary conditions applied at these reference points are defined in order to have the reproduction of the only traction test with arm.

The first results that were obtained by the new configuration are shown in fig. 4.2.C-6.
The results were not so close to the test data, therefore it was necessary to improve the settings in order to arrive at better results.

Considering the applied displacement used to generate the force this value could be increased because the upper beam stiffness of the traction test machine was much higher than the recliner stiffness. This means that the starting value of traction length was changed from 37.35 mm, that had a difference respect to the test data (40.762 mm) of 8.37%, up to 40.35 mm, having so a difference reduced at 1%.

Another improvement was done considering a different configuration of the material characteristic curve going to increase the yield stress from 420 N/mm$^2$ up to 435 N/mm$^2$. This is possible because the value of the yield stress is statistically defined and so it can change a bit around the defined value.
The results are shown in fig. 4.2.C-7.

**Figure 4.2.C-7.** Results of a Simulation with Modified Release Steps.

These results were closer to test data results than the previous ones. Considering some other changing there was possibility to assess more refinement for the setting arriving at better results.

The main last improvement was done considering the right thickness of the recliner. Having a deeper check of this dimension by a caliber it was confirmed that it wasn’t 3 mm, as defined by the specifications of the product, but it was an average closer to 3.1 mm.
Furthermore the stiffness of the spring was refined to have a better matching of the slope in the region of the second step. The final results can be seen for some simulations in fig. 4.2.C-8.

![Double cycle test with release steps](image)

**Figure 4.2.C-8.** Refined Results of Some Simulations with Release Steps.

Furthermore, the most similar result to the test data that was obtained by this simulation is shown in fig. 4.2.C-9.
Figure 4.2.C-9. One of the Simulation Plots Showing the Most Similar Results Compared to the Test Data.

Also the deformed shape of the recliner for this test can be seen from three views in fig. 4.2.C-10.
Figure 4.2.C-10. Deformed Shape of Optimum Simulation Result with Release Steps.

By this last figure, it is possible to see that the maximum stress region is in the upper part of the recliner, where there is the change of geometry between the two plane parts of the component.
Primary objective for obtaining the results of the analysis was to compute the dimension of the arm changing due to the deformation of the recliner in both the experiment and the simulation. Necessarily the bottom part section of the recliner was constrained to the seat. Thus the center of rotation described as it was moving on an axis which was converged to that constrained section.

Hence the scale of the arm was never consistent but changing in every single time increment. To define this point and to compute the arm dimension, two points were picked on the arm and their displacement values for each time were acquired from the analysis. Initially the two points; one of which was the top point, and the other one was picked as the center of the upper whole in the arm direction, were defined. By obtaining the components (U1 and U2 displacements) of the two points’ coordinates.
that were affected from the rotation of the arm, the rotation angle and the center of rotation as a third point was able to be computed by the ratio. Accordingly the third point was initially the bottom point of the arm residing on the position of the rotation axis, which is shown as the red line in fig. 4.3.A-2.

Figure 4.3.A-2. Displacements of the Points Chosen for Computing Rotation Angle.

Through the displacement computation of the third point, first step was obtained by the rotation angle of the arm for each time increment. It was computed by taking the inverse tangent of the ratio of vertical and horizontal components between initial two points (fig. 4.3.A-3).
Figure 4.3.A-3. Computation scheme for the Rotation Angle. First figure showing the initial values and after a while the new dimension of the components appear as seen in the second figure.

From this point, dimension of the arm was able to be obtained from the angle and the vertical arm component. The vertical dimension of the arm was computed by the substitution of the vertical displacement of the first point (U2) from the initial vertical dimension of the arm (fig. 4.3.A-4).
Figure 4.3.A-4. Calculation of the Arm Dimension. It can be found once the rotation angle is computed.
B – COMPARISON OF THE RESULTS

The final value of the torque was computed by the substitution of two torques created by the horizontal and the vertical forces, multiplied by the arm components;

\[ \vec{T} = \vec{F}_I \cdot \vec{R}_{II} - \vec{F}_{II} \cdot \vec{R}_I \]

Figure 4.3.B-1. Reaction Forces of the Vertical and Horizontal Axis and the Arm Components.

Evidently, the comparison of the experimental and numerical rupture tests show similar results, except that some differences are seen in some regions due to multibody restrictions in the real body, and due to continuous pulling in the simulation model.
Figure 4.3.B-2. Comparison between the Experimental and Simulation Results.
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CHAPTER 5

TORQUE ANGLE CHARACTERISTICS

In addition to the experimental tests and consecutive simulations, the configuration of the simulation model for a real behavior of the seat recliner during rear collision was also created and the results were obtained and shown in a torque-angle diagram.

In the design process, the torque setting for the bolted joints is mainly determined based on experimental tests. However, due to its expensive and time consuming costs, instead of continuous repetitions of the experiments, numerical simulations are used to predict the behavior and detect potential failure modes\[XIII\]. By using the finite element method, this study aimed to develop a torque angle curve (varying in time).

During the analysis, factors like material properties and defined boundary conditions of the recliner model gave slightly shifting results for different simulation models. Different results may have misled to a different path, which could affect the seat multibody system. Therefore an accurate preparation for the simulation model was controlled to attend the correct way of calculation and correct results.

Relatively preceding analysis in this matter had been performed, however there were some configuration errors which led to wrong results of the torque-angle characteristics. The preparation of the new models and the differences from the previous old models were described in this chapter. The results were reported in the end, showing the proof of improvement.
1 – PREPARATION OF THE NEW MODELS

Two models of the same configuration were prepared for the computation of the torque-angle values; one of which is performed with a shell model of the recliner, while for the other one, a 3D model was issued, for which the aim was the realization to obtain similar results.

![Simulations Prepared by Using a Shell (left) Model and a 3D Solid (right) Model.](image)

Since the real interactions and boundary conditions are applied in the same way, configurations are made as the same for the rupture test and for the torque-angle models, except for the rope component and for the arm dimensions. Hence the detailed steps for the shell model configuration can be found in Chapter 3.2.

However for the 3D model’s preparation, similar configuration steps were followed relative to shell model. Same material properties (Fe-E 420) were used and the
boundary conditions were applied in the same way, although there were exceptions of the connection types, due to the 3D and shell model differences. For instance, some of the surfaces in shell models were defined as nodal points, like the holes (fig. 3.2-2), while for the 3D models the inner cylindrical circles were picked for the definition of the connections (fig. 5.1-2).

Figure 5.1-2. Bolt Holes Interactions' Configuration for the 3D Solid Model.

Therefore a relative adjustment has been followed also for the 3D simulation model to define the boundary conditions. Yet due to the 3D solid characteristics, the exact side of the surfaces were used and the constraints were applied on necessary sections of the model. Described previously as an example; direct contact areas, like the inner cylindrical surfaces of the holes were the points where the interactions did apply. Moreover for the bottom constraints, the surface area that supposedly exposed to stress was chosen to be restrained (fig. 5.1-3).
For some tests, a higher value of the displacement was applied to the simulation. The reason for this modification was to obtain a higher deformation and higher rotation angle, which the results were able to be used for the multibody simulation. However, for some of these tests, the segments where the deformation turned to be not useful for rotation were removed from the results’ evaluation.

On the other hand, an evaluation is followed for mesh properties of 3D solid model, due to an effect of rigidity, which was realized in the early simulation tests in the region where the deformation was very high, the usage of a 4 node linear geometric order was impractical (fig. 5.1-4).
Figure 5.1-4. Results of the Bottom Constraints for the 3D-Solid Model Analysis Shows High Rigidity.

This complication created a huge handicap, in terms of results evaluation and high force values, and despite consisting very long simulation runtimes, the choice was necessary for the application of a quadratic geometric order, which enabled a 10 node quadratic tetrahedron algorithm to be calculated. For this reason, after some trial tests and attempts to obtain results with big mesh sized models, finally a model with a smaller mesh size was used for the analysis.
Figure 5.1-5. 3D-Solid Model with Bigger Mesh Size and Analysis Result.
Figure 5.1-6. 3D-Solid Model Result after Refinement of the Mesh Size.
2 – PROPERTIES OF THE PREVIOUS SIMULATION MODELS

Apart from the new models, there were considerable differences of the previous old models’ configuration, especially in comparison with the boundary conditions and material properties.

First of all, the same material properties had been used generally for the initial simulation tests, although there were some exceptions as slight differences of the values, minimum values and for some models, maximum values.

Evidently, these differences ended up giving different stress, torque results, and wrong perceptions of the model characteristics, causing a misconception and failure for the results of the multibody system of the seat.

Secondly and more importantly, there had been diverse changes for the arrangement of boundary conditions; such changes crucially affected the model behavior during testing, giving improper outcomes.

Although the connection descriptions regarding the back part connection with bolts to the backrest, and the arm linkage to the lower seat were accurate, one of the diversifications was due to the wrong configuration of the bottom fixture of the recliner to the seat. It was only restricted around the two bolt joint holes, without considering that there is a part which connects the two joints (fig. 5.2-1).
Furthermore, the main reason of the two bolt joints was to completely restrain the recliner to the bottom seat; due to the applied load on the model attention must be paid to the bottom region to demonstrate the effect of the constraints and the surrounding components.
When the model is inspected after the test is performed, the incorrect configuration can be clearly realized from the deformed bottom area of the recliner (fig. 5.2-2).

On the other hand, another flaw in terms of boundary conditions had appeared regarding the upper joint connection of the recliner to the backrest. While the effect of such loading condition to the backrest would reflect to the whole connected area, there was only one part that was depicted to be in stress, which is the center hole which connected the two recliners; left and right, and the backrest together (fig. 5.2-3).
On the contrary, when the backrest is exposed under certain amount of loading that might cause a huge strain increase and high deformation, all the bolted and connected holes would be under stress, center having the least effect (fig. 5.2-4).

Figure 5.2-3. Upper Part Interaction Definition for the Old Model.
A concluding plain error had been made in terms of the arm dimensions. While the length should’ve been 2/3 times the length of the height of the backrest, it was defined as low (fig. 5.2-5). The resulting arm length; 443 mm was defined for the configuration of the new model. On the contrary, it had been defined as 374.5 mm for the old model. Although the effect of this definitions doesn’t introduce a significant
change to the analysis results, there is a probability to see small differences in the final part of the torque-angle curves.

Figure 5.2-5. Complete Definition of the Old Model.
3 – RESULTS OF THE ANALYSIS & COMPARISON WITH PREVIOUS MODELS

The simulation tests were performed by means of mainly static application of a certain amount of displacement values in certain direction. During the analysis, this static increase of displacement in time resulted in an increase of the load. However in the real case, the effect is not the same. In fact the load is not applied statically but it is applied dynamically following an impulse that is predefined.

![Image](image.png)

**Figure 5.3-1.** Analysis Result of the Old Model.
It can be realized from Fig. 5.3-1 that the deformation is wrong in the bottom and the stress concentration areas are around the bolt holes, which is also an erroneous consequence and it is evident that even the resulting force and torque values (Fig. 5.3-4) show a considerable difference between the new and old models.

![Figure 5.3-2. Analysis Result of the Shell Model.](image)

The analysis had been finished by the time it was possible to obtain the results as stress, strain, reaction force, and rotation values. Thus from this point forth, a series of steps were followed to calculate and demonstrate the torque-angle plots.

For the computation of torque values and the representation of the graphs, first step was to obtain the reaction force and the rotation angle (in radians) in time base. Consequently, the steps were as follows; first of all the angle that was obtained from the analysis result were converted in degrees.
Afterwards, the force values normal to the rotating arm for each time increment were computed by taking into consideration the initial slope and the addition of rotation angle per time increment;

\[ \text{Reaction Force} \times \cos((22.5 + \text{Angle per Time}) \times \frac{\pi}{180}) \]

Subsequent to the force values computation, followed were the computation of the torque by the multiplication with the arm dimension.

**Figure 5.3-3. Analysis Result of the 3D Solid Model.**

When the final calculation is finished, resulting torque values versus the rotation angle were demonstrated in the same plot for comparison.
Figure 5.3-4. Comparison of the Analysis Results of the 3D Solid Model, Shell Model and the Old Model.

Explicitly, it can be recognized from the plots in fig. 5.3-4 that the old model results shows a difference and between the shell model and 3D solid model results, there is a prior similarity.

For the modification of the multibody simulation, a simple further torque-angle model results were also demonstrated in fig. 5.3-5. The reason of the analysis and the results of the modification is broadly discussed in Chapter 6: ‘INTEGRATION OF THE RESULTS WITH MULTIBODY SIMULATION’.
Figure 5.3-5. Result of a Single Analysis to be used for the Multibody Simulation.
CHAPTER 6

INTEGRATION OF THE RESULTS WITH MULTIBODY SIMULATION

The main objective of the experimental and simulation tests that were performed regarding the seat recliner have led to the improvements on the configurations and definitions for its properties. Eventually, the aim through the testing process was to improve the simulation results so as to obtain closer results to that of realistic behavior. Therefore the improved simulation model properties could be integrated and helped to improve the multibody simulation model. The multibody model included all other components of the seat and it had been created for the purpose of a complete simulation that could give such results, like the angular displacement, angular velocity and angular acceleration of a crash test, which had been previously performed experimentally. In the end, the priority was to obtain approximate results as close as possible compared to the experimental results. This approach of obtaining a similar behavior to the experimental case would help regarding development and optimization, so that the design of the whole seat, or some components of the seat could be improved.

The importance of the multibody simulation phase can be realized when the attention is paid to the completeness of the process of design and when the results were crosschecked with experimental analysis results.
With the recent improvements of the design processes, though there are significant differences in terms of materials, costs and performing of the methods, always the complementary analysis of experimental and simulation tests are followed for the design processes.

Simulation is an attractive, cost-effective approach for design applications. However since there is not a hundred percent availability for the setting of simulation, some errors always exist, which may not be quantified and realized, it is never certain whether the simulation results would lead to valid conclusions.\[XIII\]

Although not extracting complete trustworthy results, simulation results can be demonstrated in agreement with experimental results. Thus, the correctness and the completeness of the physical model can be controlled and validated. On the other hand, it can be clearly realized that experimental measurements can be incomplete and may subject to significant uncertainties and errors. For the desired progress, it is usually required that simulations and experiments are seen complementary, and not competitive approaches.\[XIV\]

Regarding the two approaches, a multibody simulation model had been created to obtain simulation results to be compared with the experimental results. The model had been constructed by the Simmechanics\textsuperscript{®} software, and the properties for the main components, which have a major role in terms of the interaction with the applied test conditions, were inserted as blocks in the model (fig. 6-1).
Figure 6-1. A Part of the Scheme Showing the Blocks of Models Created in Simmechanics®.

Further in depth analysis were performed on the seat recliner, which were described broadly in previous chapters, by applying traction, torque-angle, and rupture tests. The resulting moment exploited from the torque-angle tests, as a function of its rotation angle is used in the multibody model (fig. 5.3-5).
Figure 6-2. Representation of the Simulation Model demonstrated by Simmechanics® software. The model involved the Structure of the Main Components of the Seat, and the Manikin.

When the simulation model ran, the results; angular displacement (spostamento angolare), angular velocity (velocità angolare) and angular acceleration (accelerazione angolare) in function of time were able to be obtained and comparison with the experimental results was possible (fig. 6-3).
Figure 6-3. Comparison between the improved multibody simulation results and the experimental results; shown by the plots of angular displacement, velocity and acceleration in function of time, respectively.

It can be realized from the figure that the initial time sections in all three plots show a proximity and overlapping to the experimental results and general behavior from both approaches looks to be similar. Subsequent to the next time sections, the error becomes to appear increasingly due to strong non-linearity of the experimental results, along also with the behavior of the seatbelt and its retention during the impact, which substantially requires a further refinement of the models. [XV]

Still the results have proven that the simulation model is validated considering the similarity between the experimental and the numerical outputs. Moreover, not only the multibody model, but also the torque-angle models’ further validation was ensured with these results.
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CHAPTER 7

CONCLUSIONS

This project mainly followed the means of a numerical approach to improve the possibility for a better design of the sports car seat. On the other hand, the focus in this approach is made on the main structural component of the seat, in terms of the safety in case of rear collisions; the recliners. However, this project is a small part of the development process, which aims to reach an entire system with its whole complexity to arrive a design of the seat.

Within this project, each steps were important to arrive at a validated simulation model, so as to improve the knowledge of the seat behavior and to reach a new way of design. In this matter, the pursuit was done to ensure the accuracy and the quality of the simulation model to meet the required numerical results.

For this reason, performing the initial traction tests was the primary step to understand and define the numerical approach, so that the models’ feasibility to be used for the following tests was confirmed. During this validation, further refinements were required for the traction test with the arm, to show the effect of the two tests performed on the same component.
The numerical approach now could be performed for the rupture test, where the experimental tests had been done and the results were reported in other research papers. Application of the rupture test soon after demonstrated that the simulation verified the experiment, and that similar results were obtained.

After these numerical tests exploited a similar behavior with the experimental approach, the process was followed by the improvement of the torque-angle characteristics. By the time the simulation results were obtained, it is realized that there is a clear difference between the previous configurations of simulations and the new ones, and the improvement was duly considerable.

Later on, these results were able to show the proof that torque-angle plots could be imported into a multibody system of the seat model to compare its results with the experimental crash results. The results shown similarity in some regions, while there were also varying differences of the values in other regions. This requires a further refinement in the models to obtain more similar behavior. The nonlinearity, due to environmental effects of the real tests always challenges the simulation models in this way. Still the numerical results show positive outcome, due to their tendency to follow the experimental data.

Having followed all these steps and having these tools (numerical models) defined by this project, optimization of the existing seat recliners or complete new design(s) of new component(s) will be possible to be developed.

Briefly, an aspect should be extracted from this project; the aim of the work does not lay on directly by the enhancement of the properties (stiffness, strength) or refinement of the design of the seat, and its components. Whilst the definition of the models with a deeper understanding of the behavior of the seat is required to overcome and to raise the performance for current and also forthcoming design procedures.

[II]  Ferrari F12 Berlinetta Interior:  


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