

Investigation of seat modelling for sled analysis and seat comfort analysis with J-SEATdesigner

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1 Abstract

Recently vehicle model is becoming more detailed and complex. Due to refinement of vehicle model, automotive companies are demanding to directly evaluate dummy injury criteria in crush analysis. To evaluate injury criteria, more detailed seat model is needed, because injury criteria are highly depending on seat structure and restraint system. Seat structure consists from metal frame, foam pad, covering fabric and complex mechanism. Especially, residual stress in foam pad and covering fabric coming from their assembling process is not negligible for direct injury criteria evaluation. The residual stress is also important for seat comfort evaluation. However engineer needs to make big effort to take the residual stress in their seat models into account.

We have been developing new integrated seat design system named J-SEATdesigner. The concept of J-SEATdesigner is to provide big benefit for the seat design related engineer to resolve their issues. In July 2014, we released first version which is dedicated on automation for sled model assembling process. Toward the next release, we have been developing new tools on J-SEATdesigner to make more detailed and complex seat model easily and efficiently.

In this paper, our investigation for detailed seat modelling and introduction of new seat modelling tools on J-SEATdesigner will be shown. Regarding the seat modelling investigation, the seat covering processes simulation from two dimensional fabric cutting pattern has been evaluated and we will propose efficient approach for seat covering process. As new tool application on J-SEATdesigner, effect of residual stress in seat model on sled analysis and seat comfort analysis with human FE model (THUMS) will be discussed.

2 Introduction

Vehicle modelling is becoming more detailed and complex in crash simulation. Thanks to the refinement of vehicle models automotive companies can now directly evaluate dummy injury criteria using crash analysis. To do this more detailed seat models are needed, because injury is often highly dependent on seat structure and restraint system. In addition to the above, many types of LS-DYNA analysis are performed on a seat during its design process (e.g. frontal impact, side impact, whiplash, and so on). Because these analyses use different dummy models, different load conditions and sometimes different dummy/seat positions, the engineer must understand many regulations and make a big effort to prepare all the input data. In some cases, accuracy and stability improvements made to commonly used models are only stored on local disks rather than the data server, so these improved models are not efficiently shared. Some companies are trying to centrally manage dummy models and common models (e.g. transmission, engine, steering column, etc.) for crash simulation to avoid the miss-communication mentioned above. To meet these demands, JSOL has decided to develop a seat design system named J-SEATdesigner.

3 Introduction of J-SEATdesigner

3.1 System concept

The main objective of J-SEATdesigner is to provide high accuracy results of seat related simulations for all engineers without special effort and knowledge. This means that the engineer who has no information about crash regulations can run sled simulation and have high accuracy results for JNCAP, Euro-NCAP, US-NCAP, etc. To achieve this objective we need a framework that can cover following requirements:

- Easy setting and user-friendly GUI
- Management system for models
- Include information for seat design related regulation and assessment
- Easy to improve models for high accuracy results
- ID free system

Primer, developed by Arup, is one of most powerful pre-processors for LS-DYNA. Primer has several features for automotive application like dummy/seat positioning, seatbelt fitting and seat foam deformation with and without using simulation. However operation of these special features is not easy for the entry-level user because of the need to understand these features and set several parameters to get proper results. To efficiently use these features the user requires a new graphical interface as few input parameters as possible. We developed J-SEATdesigner as a seat design system in Primer to meet this requirement.

J-SEATdesigner consists of four systems as below:

- Graphical user interface
- Database management system for models and related information
- Automatic assembly system
- Seat modelling system

In the current version (ver. 1.1) we focused on making the framework for an automatic sled model assembling system, and as yet the seat modelling system has only a few features. We are planning to implement several seat modelling features to improve simulation accuracy in the next version. In the next section several useful features in ver1.1 are introduced.

3.2 Main features in automatic assembly system

3.2.1 Automatic dummy and seat positioning

To perform dummy and seat positioning, the user only has to activate positioning buttons of seat back angle and seat cushion position for the seat, and torso angle for the dummy. Based on the information in the database, J-SEATdesigner automatically identifies where positions of hands, heels and toes should be in the assembled model. Fig.5 shows example of positioning with same dummy and different vehicle body (BIW) model. As shown in fig.5, the dummy's feet are on the pedals in both cases, however the dummy's hands are located on the steering wheel in fig.5a and kept at the initial position in fig.5b. This is because the BIW model in fig.5a has target points on steering wheel for hands but the BIW in fig. 5b has no target points for hands. If the refitting button is activated, after dummy and seat positioning the seatbelt is refit to the new position. Fig.6 shows several refitting results. Fig.6a shows seat belt refitting of a loose seat belt that occurred after seat positioning. Fig 6b shows refitting in the case of a penetrating seat belt that occurred after dummy positioning.

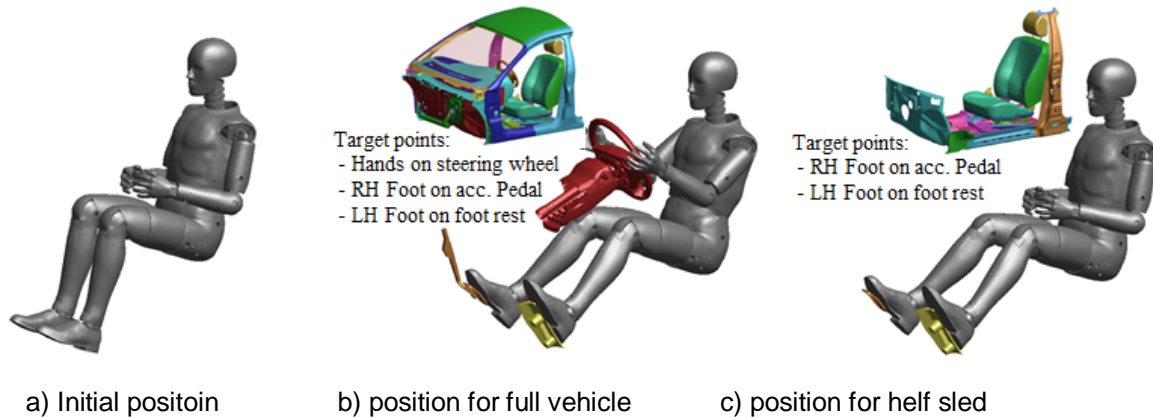


Fig. 1: Dummy positioning with different BIW model

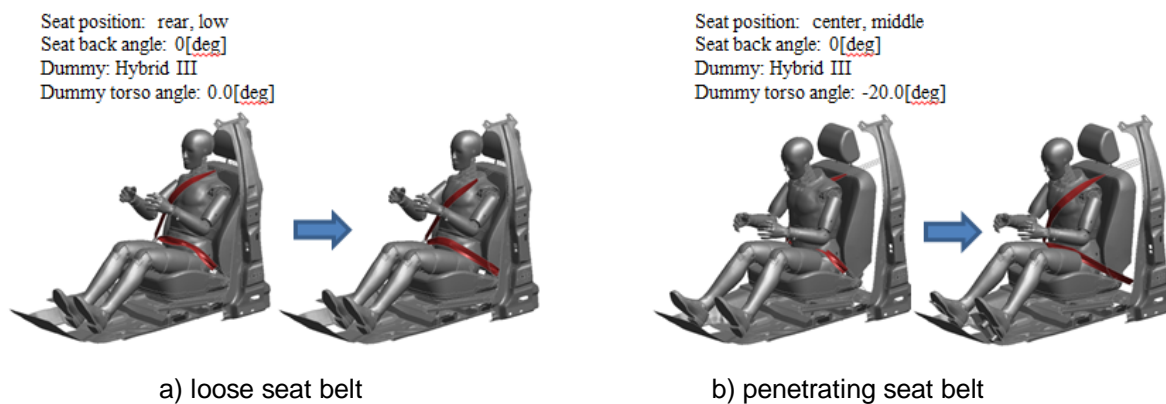


Fig.2: Seatbelt refitting results for different seat/dummy position

3.2.2 Seating simulation and import seating simulation results

J-SEATdesigner provides two types of seating simulation method. The first we call a kinematic based method. "Kinematic" means to calculate the deformed geometry of seat foam without stress calculation. In this method, coordinates of internal nodes of seat foam are interpolated from surface nodes positions which are prescribed by contact between dummy surface and seat foam. Thus some internal node coordinates may not be realistic. The second is an LS-DYNA based method. Here the deformed geometry is the result of a seating simulation with LS-DYNA and material properties in seat model are fully considered. In the first version of J-SEATdesigner the dummy model is made rigid for the seating simulation. After the seating simulation the deformed geometry is registered in the database and can be imported during the automatic assembly process. Thus the user does not re-execute the seating simulation if it has already been done before. J-SEATdesigner uses "*INITIAL_FOAM_REFERENCE_GEOMETRY" to set initial stresses of seat foam in the sled simulation. Some examples of imported seat deformation are shown in fig.7. In these examples the seating simulations have been done in advance so user can select either seat deformation without any calculation.

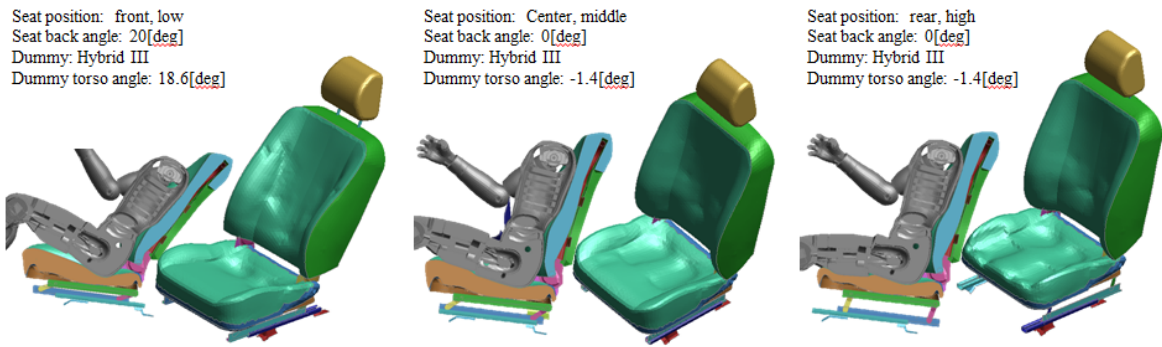


Fig.3: Imported seat foam geometries for several seat/dummy positions

3.2.3 Simulation base THUMS positioning

THUMS is one of the most detailed human FE model and has quite complex structure of the spine, elbow joint, knee joint, and so on. This precise modelling helps us to investigate injury of human under impact loading and seat comfort but makes model positioning more difficult. Unlike FE dummy model, THUMS has no kinematic joint definition (*Constraint_Joint_XXX) at moving parts. This means that almost pre-processor cannot move THUMS parts to desired position with kinematic calculation. One good approach for THUMS positioning is simulation based positioning. The simulation requires “know-how” to get proper deformation of moving parts. J-SEATdesigner has THUMS positioning panel which helps you to make input deck for THUMS positioning simulation. This panel provide two different user input for positioning. First input is specifying angles for each joint and second input is to specify distance vector to your target point. Second input is same input required in automatic assembling process for FE dummy in J-SEATdesigner. This positioning procedure is also implemented in automatic assembling process of J-SEATdesigner. Thus user can use THUMS like usual FE dummy model in J-SEATdesigner. Fig.4 shows positioning simulation results for THUMS sled test. Each joint angle is calculated by distance from initial points of hand and foot to their target point. Detailed value of each joint is shown in table 1.

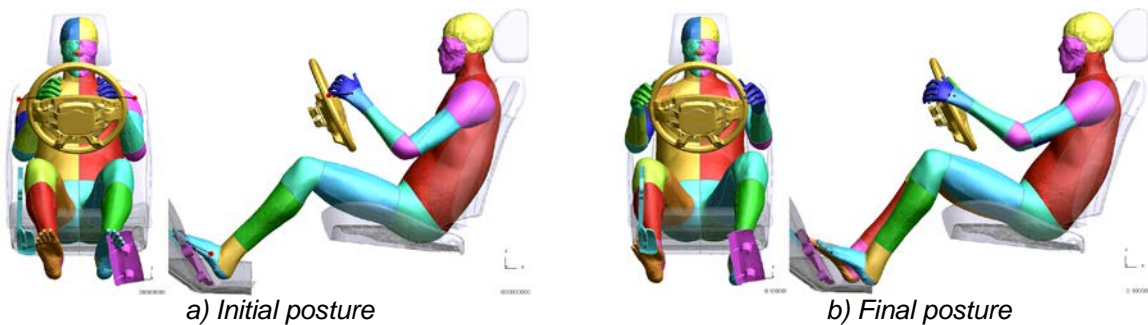


Fig.4: THUMS positioning results based on pre-calculated joint angles

Distance vector		Joint angle (deg)	
Right hand	(-69.0, 93.9, -11.7)	Shoulder (ball joint)	8.58
			7.44
		Elbow (pin joint)	22.18
Left hand	(-86.8, -76.6, -7.5)	Shoulder (ball joint)	11.84
			4.03
		Elbow (pin joint)	28.45
Right foot	(-27.7, 88.0, -23.4)	Hip (ball joint)	0.05
			6.51
		Knee (pin joint)	3.76
		Ankle (pin joint)	1.57
Left foot	(88.9, -55.9, -44.0)	Hip (ball joint)	4.09
			6.29
		Knee (pin joint)	16.66
		Ankle (pin joint)	6.15

Table 1: Calculated joint angles from desired distance vector

3.2.4 Simulation base H-Point measurement

The H-point is an important piece of information to run a seat related simulation. In general the H-point position is measured by experiment and cannot be determined without the real full seat structure. To evaluate the H-point position without real a seat structure, J-SEATdesigner has simulation based H-point measurement feature and uses the Arup H-point manikin FE model. To run simulation based H-point measurement, the user adds new case as "H-point measurement simulation" and selects a suitable regulation in project management panel. Supported regulations in the current version are SAE, ECE and Japanese safety standard. The H-point measurement steps in these safety standards are as below:

1. Put the manikin on seat
2. Adjust position of leg and foot
3. Move manikin forward to remove penetration with seat
4. Apply load on T-bar
5. Put weight on torso, buttock, thigh and leg
6. Apply load on back angle bar
7. Measure the coordinate of H-point

In J-SEATdesigner, steps 1 to 3 are done automatically as a pre-process and then an LS-DYNA input deck for steps 4 to 6 is generated. After the LS-DYNA calculation, J-SEATdesigner reports the H-point coordinate from the result.

4 Investigation for detailed seat modelling

4.1 Fabric/leather material property

Several types of fabric and leather are used for seat cover. Typical fabric material has anisotropic and non-linear property under tensile loading and shear loading. Because of their woven architecture, some fabrics show over 0.5 in macroscopic Poisson's ratio. This means that it is not easy to measure fabric material properties. KES (Kawabata evaluation system) is testing system to measure the mechanical properties of fabrics. KES is composed of four different machines on which following six tests can be performed.

- Tensile and shear test (loading/ unloading)
- Pure bending test
- Compression test though the thickness
- Surface test (surface friction and roughness)

MAT_FABRIC (form=-14) is used as fabric material in LS-DYNA. This material used not to be able to calculate bending stiffness because this material is implemented for membrane shell element, but recent LS-DYNA can accept not only additional elastic modules as coating layer to calculate bending stiffness but nonlinear curve input for tensile loading, unloading and shear. Fig 5, 6 and 7 shows experimental results and material validation results for three different types of materials (Real leather, suede-like artificial leather and jersey knit fabric). Real leather is stiffest material in these three materials and jersey knit fabric shows strong anisotropy in tensile loading and bending. For tensile and shear properties, MAT_FABRIC shows good agreement with experimental data for all type of materials. However, due to the elastic input for coating layer, this material model cannot represent anisotropic bending behaviour. Thus, in this paper, we used weaker bending behaviour as fabric/leather property. Measured friction coefficients for each fabric/leather are shown in table 2.

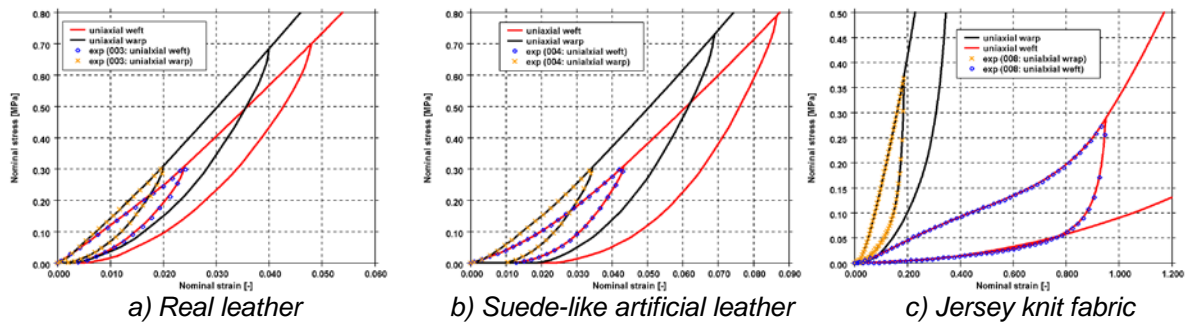


Fig.5: Fabric / leather Tensile material property (tensile)

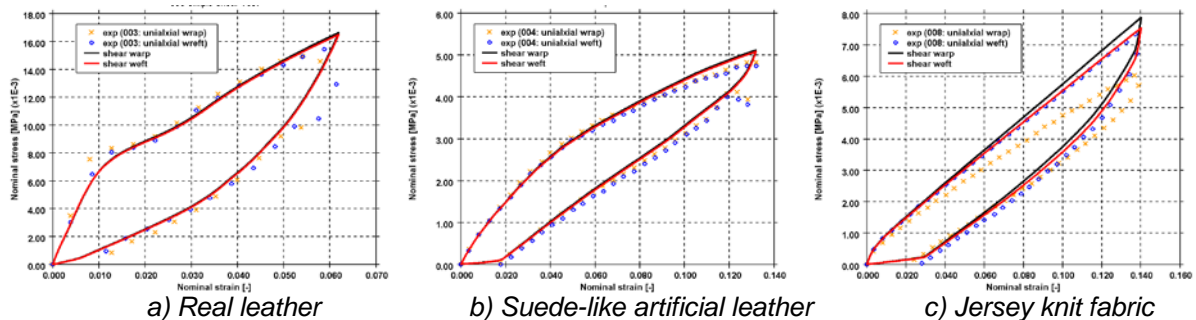


Fig.6: Fabric / leather material property (shear)

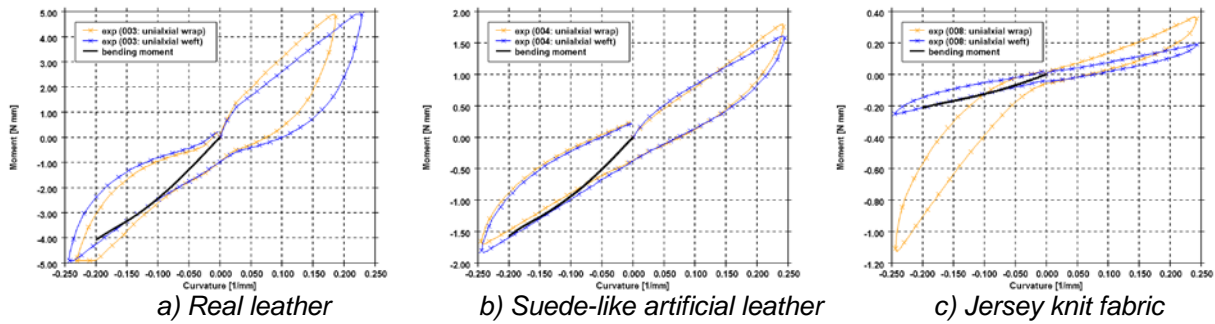


Fig.7: Fabric / leather material property (bending)

Real leather	Suede-like artificial leather	Jersey knit fabric
0.13	0.4	0.17

Table 2: Fabric / leather material property (friction coefficient)

4.2 Covering simulation

To consider residual stress after covering process in sled analysis and comfort analysis, the covering simulation is needed. Covering process is composed of three steps. First step is sewing. 3d seat cover geometry is generated from 2d cutting pattern in this step. Second step is hooking in which seat cover is connected to some points of the wire on the cushion surface. Final step is covering. In this step, seat cover is pulled with proper tension to remove wrinkle of seat cover. These steps are modelled by some discrete elements lied on sewing lines, connecting points and pulling areas. Each discrete element has initial stress to set its length zero. Material properties of seat cover are defined by experimental data as mentioned in section 4.1. Fig.8 shows case study of seat covering simulation. In this case, the initial foam geometry is hemisphere and 2d cutting pattern for the cover is 4 triangles. Because this cutting pattern is not optimized for hemisphere geometry, final covered geometry is not hemisphere.

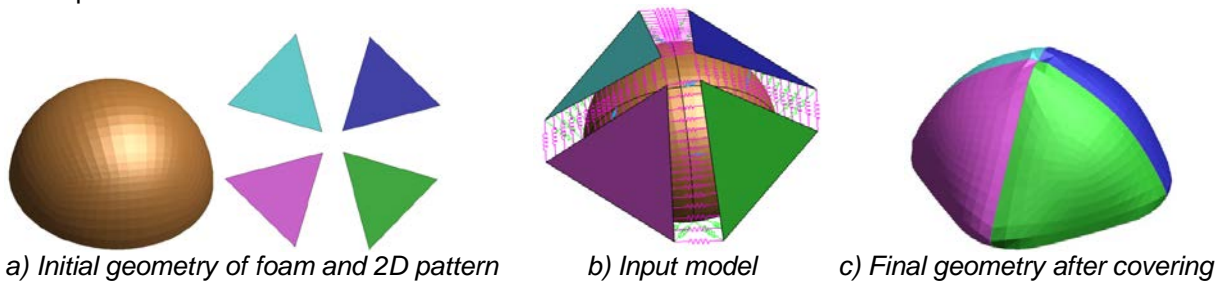


Fig.8: Covering simulation for hemisphere

4.3 Flattened pattern prediction

As shown in section 4.2, flattened cutting pattern should be optimized to have desired covered geometry. The iterative method is one of popular way to optimize the pattern for desired covered geometry. But we can roughly predict the optimized pattern with LS-DYNA by assuming simple elastic material as seat cover material. Inverse solver in LS-DYNA is powerful solver to find flattened geometry from product geometry in metal forming. Although this solver only supports isotropic elastoplastic material, this solver can be used for prediction for flattened pattern from sewing line and foam geometry. Fig.9 shows the case study of pattern prediction for flattened for two different sewing lines with LS-DYNA inverse solver. Final covered geometries for each sewing line are shown in Fig.10. As you can see in Fig.10, final covered geometries are hemisphere although two sewing lines are quite different. These results shows that LS-DYNA inversed solver can be used for seat cover cutting pattern prediction.

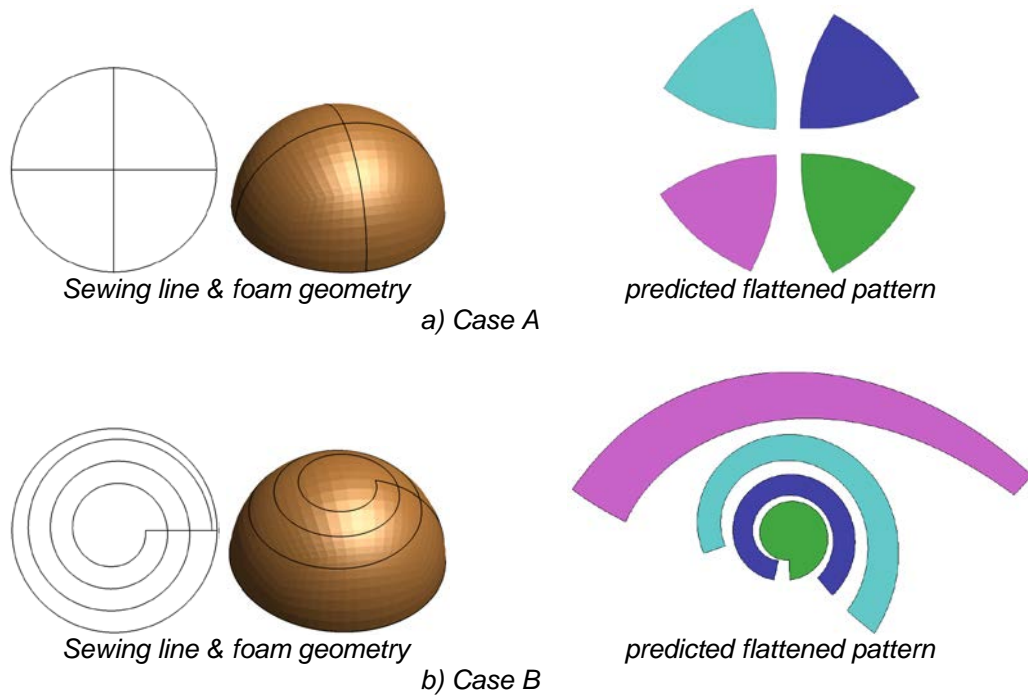


Fig.9: Flattened pattern prediction for two different sewing line

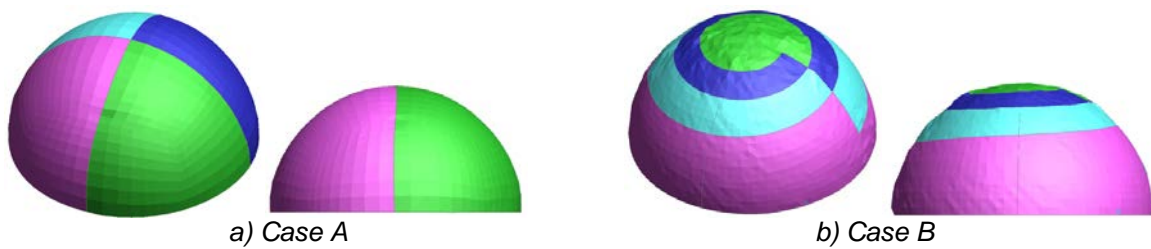


Fig.10: Final covered geometry

4.4 Effect on comfort analysis

4.4.1 Covering simulation for seat structure

Covering simulation for seat structure has been done with three different kinds of fabric / leather. Fig.11 shows foam geometries and cutting pattern for seat back and seat cushion. As material properties of seat cover fabric, we assumed real leather, suede-like artificial leather and jersey knit fabric that is discussed in section 4.1. In case of real leather, the deformation during covering simulation is shown in Fig.12. Because the seat cover is not put on the seat foam yet, a lot of wrinkles on the cover are observed after sewing step. After applying proper tension in covering step, almost all wrinkles are removed in final geometry. Fig.13 and 14 show maximum principal stress and maximum principal strain with real leather, suede-like artificial leather and jersey knit fabric.

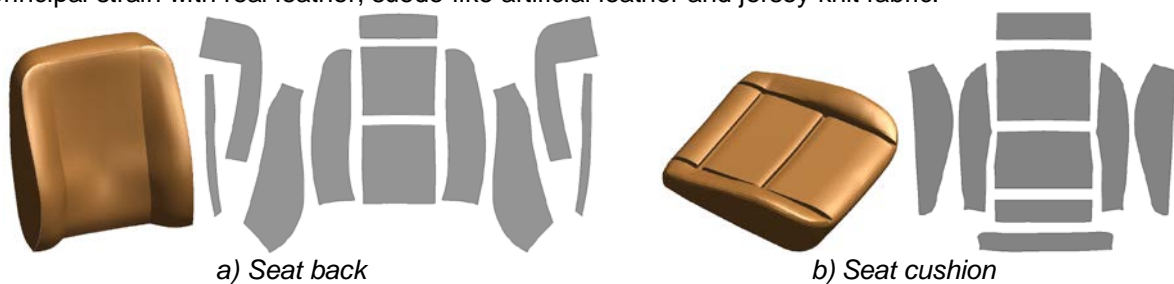


Fig.11: Form and cutting pattern

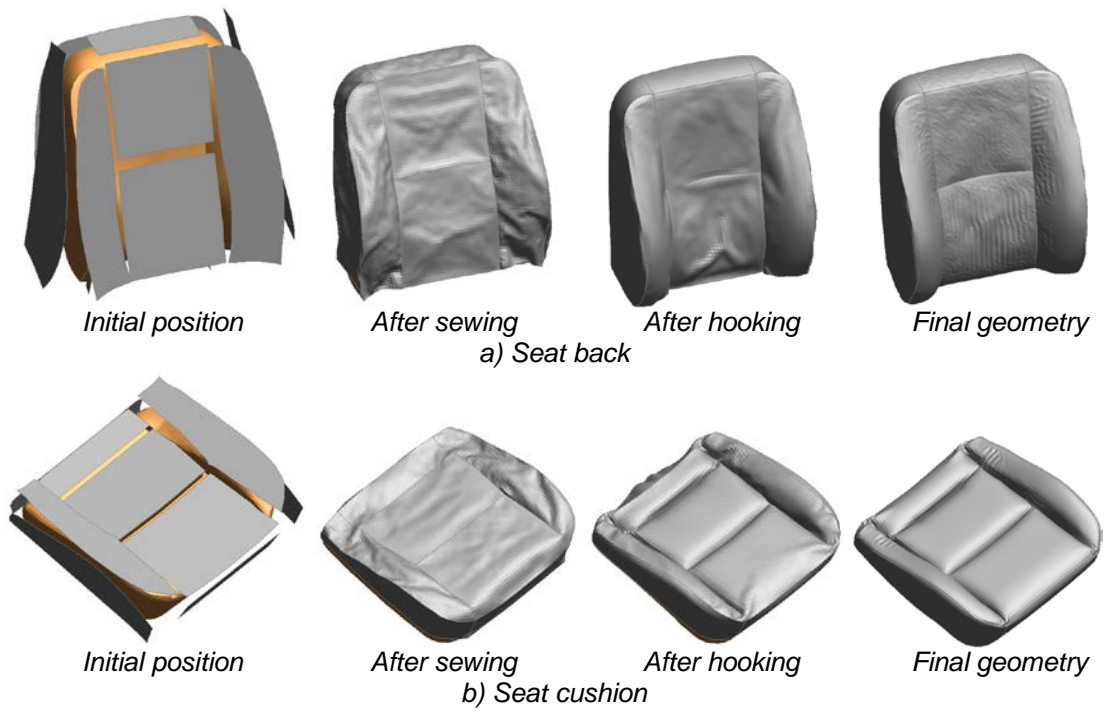


Fig.12: Covering simulation result (Real leather)

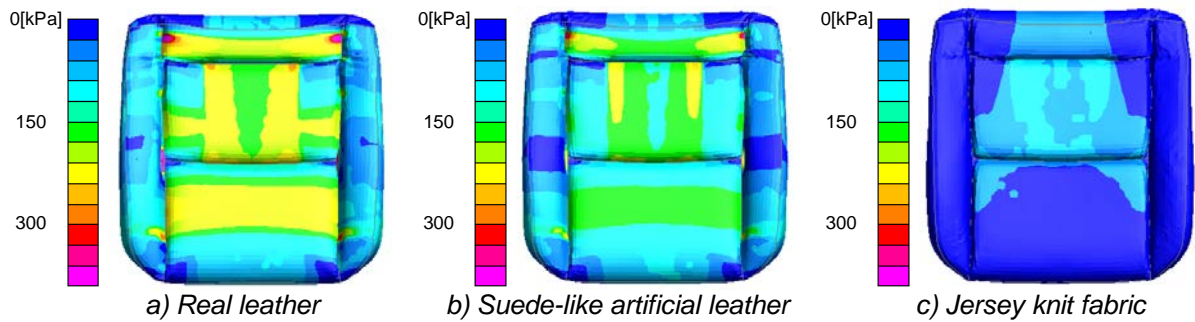


Fig.13: Residual max principal stress in fabric/leather after covering simulation

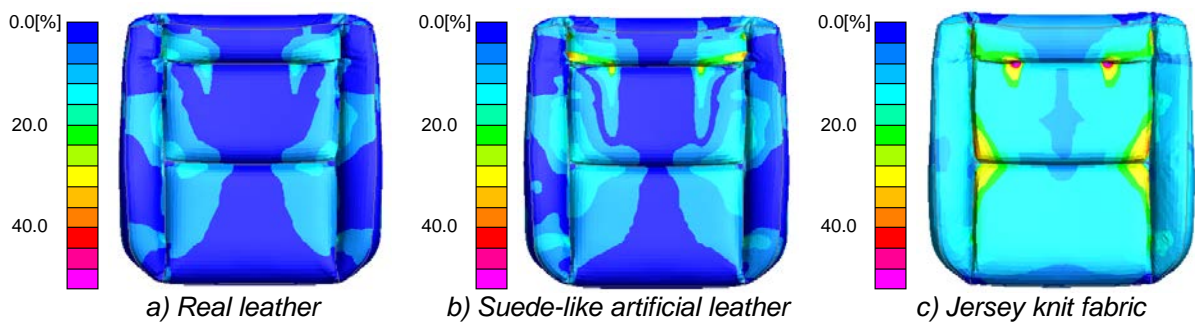


Fig.14: Residual max principal strain in fabric/leather after covering simulation

4.4.2 Comfort analysis with rigid dummy

Compressing seat foam with rigidified dummy has been performed to evaluate seat comfort. To discuss effect of residual stress in seat foam and seat fabric on the comfort, two simulations have been done with the residual stress and without the residual stress. The residual stress in seat form

and seat fabric is considered by using two keywords (*INITIAL_FORM_REFERENCE_GEOMETRY and *AIRBAG_REFERENCE_GEOMETRY). The rigidified dummy was moved by displacement not by gravity loading to simplify the simulation setting. Fig.15 shows contact pressure distribution on seat cushion surface. In case of considering residual stress, lower pressure at hip area can be observed. We cannot predict applied pressure on human surface under gravity loading because the dummy motion was prescribed by displacement in these simulations. However this results indicate that the applied pressure will be reduced with considering residual stress in the foam and the fabric.

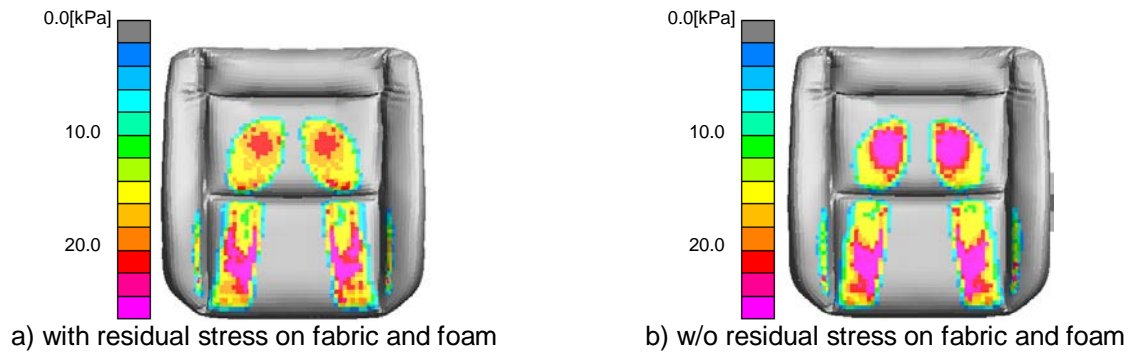


Fig. 15: Contact pressure on cushion surface

5 Next version

Our goal of J-SEATdesigner is reduction of workload when modelling seat related simulation and providing an environment for high accuracy results without any know-how about seat related simulation. Thus we are continuing to develop J-SEATdesigner to extend the application for general seat structure evaluation in LS-DYNA. Now we are doing R&D and implementing the following features for the next version:

- Seat modelling tool
- Material identification tool
- Support new regulation
- Support child seat

6 Conclusion

In this paper we show the J-SEATdesigner concept and some useful features for seat simulation in LS-DYNA and our investigation for seat covering process simulation. This investigation is implementing in next version of J-SEATdesigner that will be released at the end of this year. J-SEATdesigner is not a simple preprocessor but an integrated system to assemble models efficiently and avoid time loss coming from miss-communication between each engineer. In addition, J-SEATdesigner is designed based on over 20 years' experience in automotive crash simulation. By using J-SEATdesigner, all users can obtain our know-how for automotive crash simulation without any effort and spending time. We hope that J-SEATdesigner helps engineers who need seat related simulation to have useful simulation result in LS-DYNA.