HYBRID PROTOTYPES TO ASSIST MODELING AUTOMOTIVE SEATS

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Abstract

The development of new modular seats is an important issue in the automotive industry. However, is very time consuming and costly. Virtual models and hybrid prototypes could accelerate the car seats development process. The hybrid prototypes are mainly manufactured by rapid prototyping with multi materials. The objective of this paper is to establish a methodology to develop innovative lightweight multi-functional, modular car seats to be used in Multi-Purpose Vehicles (MPV), by means of FEA simulation and rapid prototyping additive/subtractive technologies utilizing multi materials. A case study is presented to validate the developed methodology. The manufactured hybrid prototype's reproduces the main functionalities of the MPV modular seat, namely its three key positions: normal, stored and table.

Introduction

Today manufacturers experience immense pressure to provide a greater variety of complex products in shorter product development cycles. The evolution of the market needs the time-to-market reduction, mainly because the product life cycle is shorter and also because it is very important to produce more rapidly from an initial conception or "idea" to a mass production product. New approaches in rapid product development (RPD) from the design point of view are needed [1]. The late discover of product requirements are fairly common and the use of certain methods and product representations or materializations may reduce this problem. The identification and implementation of designer requirements in the early stages of RPD are significant issues for a successful product development reducing time [2]. These needs, coupled with the desire to further reduce costs and improve quality have impelled manufacturers to turn their focus toward integration of product design with faster manufacturing process activities. One possible methodology to achieve this goal is through the use of rapid prototyping (RP) technologies giving the ability to transit quickly from concept to rapid solid freeform fabrication reducing costs and improving product quality faster. RP represents technologies that quickly realize the conceptualization of a product design. The evolution of RP allows obtaining parts representative of mass production products within a very short time.

The main advantages of virtual prototyping (VP) in the RPD context consist in the ability to alter earlier the shape at the designer's will, directly in CAD format. The design visualization or virtual prototyping (VP) can also be carry out handling stereolithography tessellation language (STL) models, the de facto standard for layer manufacturing technology (LMT) [3]. The VP in the RPD framework allows finite element analysis (FEA) simulation techniques of intermediate geometric models to optimize the design prior to fabricating the physical model. Careful examination of the visually simulated model before the actual fabrication can help minimizing unwanted design iterations [4]. From the improved VP can be manufactured conceptual models by rapid prototyping (RP) in a short time (or mask time overnight) to evaluate the set up corrections. RP provides true CAD design verification, because digital data is used directly to manufacture a cost effective prototype.

The basis of rapid prototyping technology allows the rapid SFF of models built by additive and/or subtractive RP [5]. The rapid production of a prototype make available manufacturers having a better product development overall control, not only of the product itself - visual aids for engineering, ergonomics, and fit - but also of the processing technology by having a prototype at an early stage of the rapid manufacturing process chain. RP responds better to the growing interest of the industry in reducing the time to market of new products and respective costs [6].

The RP in wax material can be obtained directly by multi-jet modelling (MJM) techniques. The surface finish and dimensional precision of parts obtained through this rapid prototyping process is often highly important, especially in those situations where the manufactured prototypes are used as functional lost patterns, as in the investment casting technology [7]. The RP wax pattern dimensions are determined by the wax's thermophysical and thermomechanical properties and RP process parameters [8].

The principal bridge between RP and SFF is based on the indirect use of STL geometry data files for additive and/or subtractive manufacturing. These tessellated representations of products have several drawbacks linked to the shape and topology of the surface triangular mesh.

The virtual prototyping simulation and analysis in the RPD methodology contest provides the ability to adjust earlier the geometric shapes to fulfill the design requirements prior to fabricating the corresponding solid freeform physical parts [9].

RPPD Methodology

The purpose of this R&D work was to investigate the crucial roles of RP technologies and purpose a practical methodology to integrate advanced rapid technologies in simultaneous engineering for rapid product and process development (RPPD). The developed methodology provides meaningful information for manufacturers to integrate VP/RP/RE/SFF technologies that are best suited to their production requirements in order to reduce the product development leading time and reducing manufacturing costs.

The rapid product and process development (RPPD) methodology for rapid product development integrating VP/RP/RE/SFF is schematized in Fig. 1.

The RPPD methodology starts with the product specifications from designers and the 3D-CAD design serves as the starting point in the integration of product and process development allowing starting the production in a shorter time. Once the 3D-CAD design has been analyzed and the corrections completed, it serves as a link to utile rapid prototyping for solid freeform fabrication process.

In this study, the RPPD methodology linked with several technologies includes: CAD software to generate file data models based in functionality and ergonomics (*.stl format); virtual prototyping for preliminary FEA stress analysis; SFF technologies to built conceptual prototypes; simultaneously the metrology control is perform aided by reverse engineering; rapid SFF of physical hybrid prototypes by composite technology, followed by surface finishing; functional tests with the physical hybrid prototypes. After some iteration to improve the product performance and enhance the manufacturing process in a short lead time, they are approved and the mass production could start.

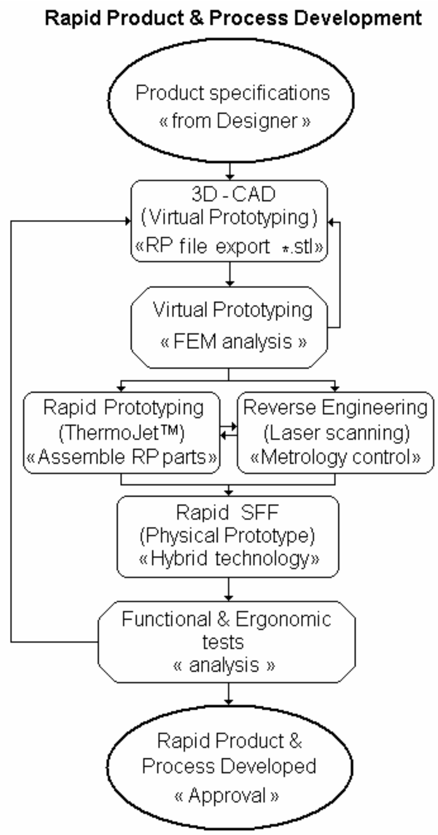


Figure 1 – Methodology for Rapid Product & Process Development.

The actual know-how in RP allows saying that it is important to utilize 3D-CAD software to define parts with solid modeling capabilities in the preliminary design stage avoiding either wire-frame or surface models. A solid freeform model enables cross sectioning to expose internal details and computation of moment of inertia. The solid freeform model also allows the designer to easily determine part parameters such as weight and centre of gravity through the software. These parameters are crucial to the design evaluation of a part. The 3D-CAD and VP software serves as a powerful "tool" in design evaluation, particularly in the areas of finite element analysis (FEA) and mechanism evaluation design by virtual prototyping animating the mechanisms. FEA predicts stress and deflection on a structure or allows process simulation.

A solid freeform model of a part can be imported from a CAD system in the STL file format to a RP system. The STL file approximates the surface of the solid freeform model by covering it with a multitude of triangles. Subsequently, a RP system, which uses the technology such as fused deposition modeling, builds a part with the SFF process that grows the part in successive additive layers. Ideally, to make a good RP model, the STL file must be made from a watertight solid model. If the user manages to completely seal and close all corners and seams, any of the major CAD software packages is capable of providing true solid freeform models and consistently exporting flawless STL files. Otherwise, corrections can be made in dedicated software's. Designers can make decisions faster and iterate design changes more quickly using prototypes, saving time and energy that translates into saving product and process development costs. With a 3D model in hand, designers can easily identify costly design flaws or some manufacturing unfeasibility. As a result, modifications of a part are made early in the design process before costs escalate. Detecting design flaws with prototypes complements evaluating design alternatives with engineering based CAD software. Also the prototype accuracy controlled fast by metrology aided by scanning and reverse engineering (RE) indicates eventual geometry deviations.

The use of SFF systems enhances the integration of design. It reduces the number of costly changes as it enhances communication between the design and manufacturing departments, giving manufacturing a chance to integrate manufacturability expertise and influence the product design while changes are inexpensive. The cost of a change increases roughly by an order of magnitude as the design proceeds from the significant development phase to the next. The other advantage when using rapid SFF to make functional hybrid prototypes is that components may be manufactured with low and high resistance materials (e.g. expandable wax or polymeric materials assembled with aluminum or steel articulation joints). Some SFF functional prototypes can even be cut, drilled, tapped, sanded and finished in a number of ways for higher quality. At this point, the non-standard functional prototypes (SFF devices) can be utilized mounted as components together on testing apparatus for functional and ergonomic studies.

Numerical Modeling of the MPV Seat

The module Design aims developing a lightweight multi-functional, modular and innovative automotive seat, to be used in a MPV-type (MPV - Multi-Purpose Vehicle) City Car. The seat's external shape has been defined by designers and then draft in CATIA 3D-CAD software. The virtual prototype has proved very helpful in resolving conflicts between the seats main three moving parts, but at a given stage it was clearly insufficient as a working tool for engineering analysis. Consequently, was decided to build a semi-functional 1:5 scale prototype to serve as reference for discussions and also as a marketing tool for presentations to the community.

The numerical modeling of a light weight MPV seat aimed at giving realistic boundary conditions to the human model. The modular MPV seat consists in various mechanical elements. The main parts of the seat were: the head-rest clamp, the head-rest foam, the foam of the backrest, the foam of seat base, the backrest spring, and the cover of the seat. The geometry of the MPV seat was design based on new ideas and is illustrated in Fig. 2a.

To model the solid freeform modular MPV seat the experimental data used in this study were completed in a context of ergonomics and comfort [10 – 11].

The designer's team modeled the external freeform of the MPV seat using Rhinoceros 3D modeling software. However, this virtual model was meant to convey only the general impression of the shape and so it was composed of unconnected and nonintersecting surfaces that proved to be extremely difficult to "mend". Consequently a different approach was followed, which consist in importing into CATIA the Rhino model, using the IGES import/export standard format [12].

The exact surfaces (not class "A", but at least closed and generally continuous) were then modeled using the designers' freeform as a reference. A general overview of the process is represented in Fig. 2b.

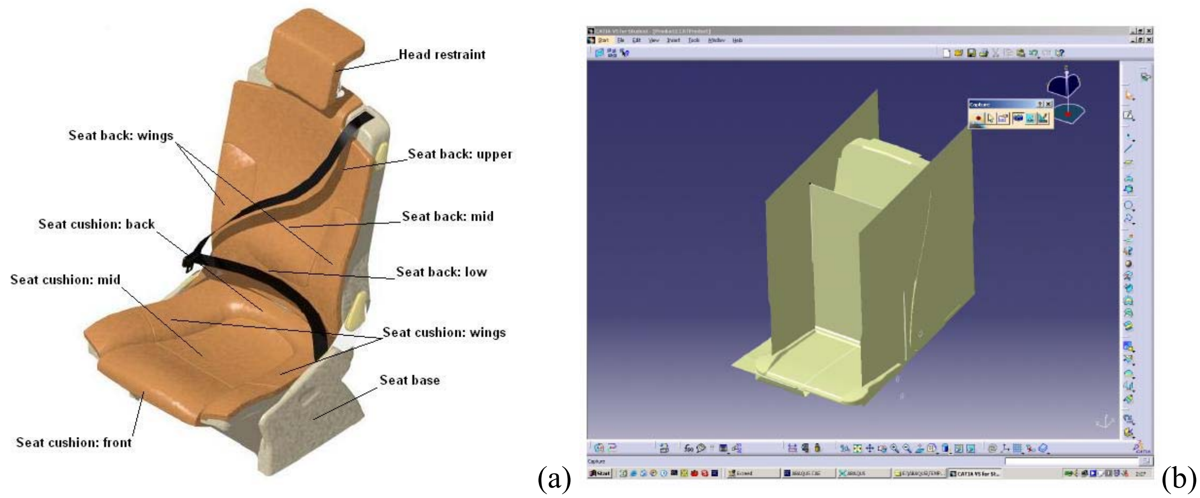


Figure 2 – a) Representation of the MPV modular seat modeled in Rhinoceros 3D software
b) The CATIA modeling process starting from designer freeform.

Simulation and FEA Analysis with MPV Model

In this study, the material behavior laws for the foam and the cover were considered linear with material properties resulting from the literature. The seat backrest and cushion were more detailed than the seat base. Thus, a simplifying hypothesis consisted to model seat backrest and cushion with flexible shell elements which aimed at limiting the movement of the human body.

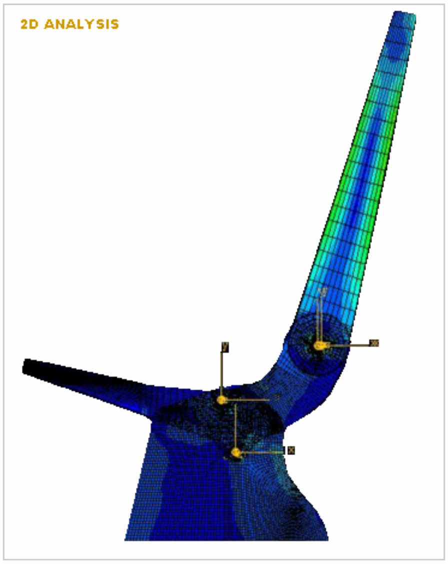
The mechanical properties of base seat was been extracted from compression tests and was considered with linear rigid shell elements and the Young modulus was of 1000MPa and the Poisson's ratio was 0.3. The thickness of the shell elements was of 3.0mm with a density of 7.9 Kg/l.

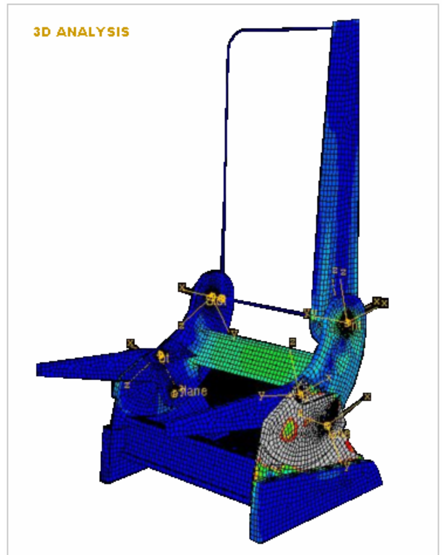
Special attention was paid to the backrest and cushion frames of the seat. The backrest and cushion frames were modeled with shell elements. The frame geometry was simplified. It was divided into three parts: the base frame considered as rigid body; the seat cushion frame which can be deformable; and the seat backrest frame also considered as a deformable body part. The normal position of the seat cushion and the backrest frame were related by a fixed articulation as a rigid body.

The material properties of the backrest and cushion steel frames were determined in order to have a qualitatively realistic behavior under static loading. We thus obtained a Young's modulus of 235MPa and a Poisson's ratio of 0.28. The density was of 550.0 g/l and the thickness of the frames was of 1.75mm. The stiffness of the mechanism between the back rest and the cushion frame were chosen very high to be considered as rigid.

<u>*Car Seat FEA Model:*</u> The first 2D analysis from simulation of the homologation test ECE-R 14 on two different light-weight seat structures, using ABACUS software was performed

only to get some feeling for the structures ability to resist the kind of loads involved, Fig. 3a. The preliminary 3D static nonlinear analysis has proved that the backrest and the base frames of the MPV axisymmetric light-weight seat structure was too weak to support the loads involved, Fig. 3b.

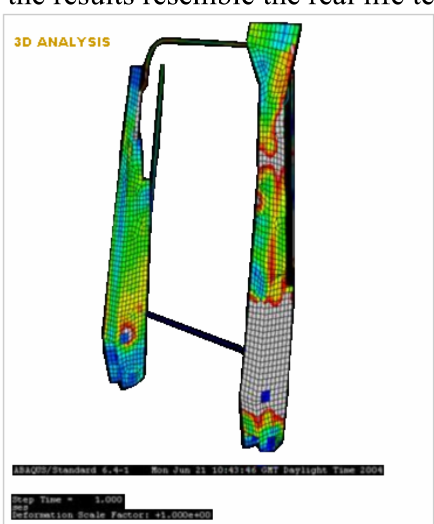


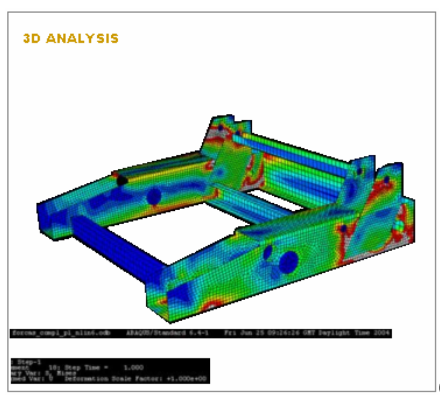
(a)


(b)

Figure 3 – a) 2D simulation on a new MPV seat structure with ABACUS software.
b) 3D static nonlinear analysis of the new MPV seat structure.

The backrest was reinforced, as shown at 3D static nonlinear analysis in Fig. 4a Also the seat base was reinforced, as shown at 3D static nonlinear analysis in Fig. 4b. In terms of general resistance, the results resemble the real life test well enough.



(a)


(b)

Figure 4 – a) 3D static nonlinear analysis of reinforced backrest frame.
b) 3D static nonlinear analysis of reinforced seat base.

Hybrid propotypes by SFF process

Preparation of Rapid Prototyping Process: In order to export a valid STL file, one must have a completely close surface. Although CATIA offers a number of tools to verify the quality of surfaces, the existence of gaps and lacks in continuity, and the ability to export a surface in STL format, experience has shown that the risk of incomplete or "wrong" prints was strong when trying to print directly from surfaces. An alternative approach was then taken, which consisted in first converting the CATIA surfaces in a solid freeform, Fig. 5, and then generating the STL file.

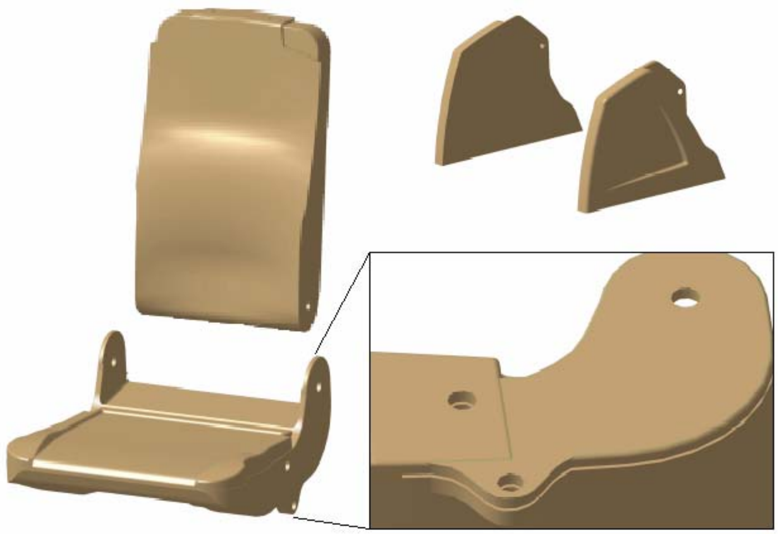


Figure 5 – Modeled SFF virtual prototype of the MPV seat and a detail.

3D Printing the Prototype: After the STL file was ready it was imported into 3D Systems' [13] proprietary software, which allows a number of operations to be carried out before starting the 3D printing process.

The most important of these operations is part placement. Since material is added to support the prototype build up its position has a strong influence on where the support ribs are fixed on the surfaces. Derived from the need to build supports for surfaces with inclinations greater than 2-3 degrees with respect to the vertical there are two types of surfaces in the final model: high quality surfaces where there were no supports and low quality rough surfaces in the places where supports had to be built. This is important, since the necessary removal of those support ribs can damage the prototype surfaces, or at least roughen these surfaces. Generally the surfaces that are vertical or facing upwards are good quality, whereas surfaces which normal is down facing are rough. The need for good quality surfaces in specific zones of the model determines the model placement within the build volume.

The functionalities that the software includes are: estimation of the total build time; STL file verification; previewing of the supports to be built and automatic part placement. Another factor that is influenced by part placement is build time. The 3D Systems' ThermoJet takes approximately six minutes to build every millimeter in height, so by carefully examining the part orientation and other requirements one can achieve the best compromise between surfaces quality and build time.

<u>*Hybrid Seat Prototype SFF by 3D Printing:*</u> In this work a ThermoJet™ solid object printer from 3D Systems, using the multi-jet modeling (MJM) technique is used to produce solid freeform physical models of designed MPV seats. This system uses a print head comprising 352 jets oriented in a linear array. The large number of jets allows fast and continuous material deposition at a resolution of 300 x 400 x 600 dpi (xyz), producing models with a maximum size of 250 x 190 x 200 mm (xyz) and with a layer thickness of 0.042 mm [14].

Making the 3D prototypes with the rapid prototyping machine involves the conversion of STL files of the parts in the machine's software. To produce the solid freeform physical model of the part, the corresponding STL file is transformed in machine code through the ThermoJet™ printer client software, powerful software that enables to verify the STL file, auto-fix errors and determine the better position of the model on the working apparatus area, optimizing both build space and time.

Solid freeform 3D printing is done layer by layer with "Thermojet 88" wax material from 3D Systems (which properties are in table 1), over the apparatus metallic platform.

Melt temperature	[K]	358 -368
Softening temperature	[K]	343
Density @ 413 K	[g/cm^3]	0.846
Density @ 403 K	[g/cm^3]	0.848
Density @ 296 K	[g/cm^3]	0.975
Volumetric shrinkage from		
413 K to room temperature	[%]	12.9
Ash content (Gray wax)	[%]	0.00 – 0.01

Table1: Properties of wax material "Thermojet 88" (3D Systems™ [13])

As the machine selected is a concept modeler from 3D Systems that has limits to the dimensions of the parts that could be printed. For that reason, was necessary to rescale the car seat geometry to a smaller scale 1:5.

The build process took approximately 3 hours to complete, after which it was necessary to cool the model down in a refrigerator for about 1 hour to facilitate the supports removal that broken easily.

After all the RP parts had been "cleaned" they were ready for the next step of the process: the custom fitting of sheet aluminum reinforcements in the zones that support rotation axles and on the lower part of the model, where the forces exerted during model manipulation would exceed the resistance of the thermopolymer. Upon assembling the SFF hybrid prototype reproduced all the main functionalities of the MPV modular seat, as shown in Fig. 6.

Figure. 6 - SFF hybrid prototype (scale 1:5) made by RP multi-jet in wax reinforced with aluminum at the zones that support rotation axles and on the lower part of the model.

HSM and Hand Finishing MPV Pure Seat Hybrid Prototype: The MPV pure seat hybrid prototype, scale 1:1, was built out of several PUR blocks that were HSM (High Speed Machined) according to the 3D-CAD geometry, Fig. 7. MDF plates were used to model the components that required extra resistance. The rotations axles are made out of steel.

Fig. 7 - The solid freeform hybrid prototype (scale 1:1) performs accurately the main movements of the MPV seat: (a) normal; (b) stored; and (c) table.

The solid freeform hybrid prototype has been fabricated by the industrial design team, respecting the placement and dimensions of the internal components. This solid freeform hybrid prototype was reverse engineered to update the original 3D-CAD geometry with the changes performed on it.

Conclusions

The present paper describes a methodology for the development of efficient modular seat models, applicable for usage in the development process of light-weight modular MPV seats. Additionally, hybrid prototypes made by SFF providing appropriate input for the seat models have been described. Hybrid prototypes are mainly manufactured by rapid prototyping with multi materials. As an example, the methodology has been evaluated for one modular MPV car seat: a virtual model of this seat has been created containing the mechanical properties requested for a real seat. The following can be concluded:

A methodology has been outlined to develop innovative lightweight multi-functional, modular car seats to be used in Multi-Purpose Vehicles (MPV). Virtual models and hybrid prototypes have allowed speed up the car seats development process. This methodology allows realistic predictions of seat design and interactions with e.g. human models.

The development of modular seat models by usage of numerically FEA simulation techniques for seat modeling is an efficient method in terms of computational time, for the development of seats. This strongly affirms the proposition that seat models are attractive for parameter variation at an early stage of the design process. The presented methodology is attractive for simulations with long CPU times that do not require a detailed analysis of deformations.

The SFF of hybrid prototype's with additive/subtractive techniques utilizing multi-materials reproduces the main functionalities of the MPV modular seat, namely its three key positions: normal, stored and table.

In a further development it will be possible to perform a parametric study on seat characteristics and optimize the seat against the biomechanical response of the human body complex.

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