Development of a Small rear Facing Child Restraint System Virtual Surrogate to Evaluate CRS-to-Vehicle Fitment

Richard Hanna[1,2], Aditya Belwadi, PhD[1]
[1] The Center for Injury Research and Prevention, The Children's Hospital of Philadelphia;
[2] Drexel University, Department of Mechanical Engineering and Mechanics, School of Biomedical Engineering, Science and Health Systems

ABSTRACT

Child restraint systems (CRS) are the leading technology in providing safety and restraint to child occupants in automotive vehicles. Their success at reducing injury in motor vehicle crashes hinges largely upon their proper installation as well as their interface with the vehicle seat. To this degree, it is immensely important that vehicle manufacturers have an accurate means of producing seat design specifications capable of accommodating the large and varied CRS market in terms of safety, comfort and aesthetic appeal. Current methods of obtaining accurate geometries and volume have long been outdated or are a poor representative. Additionally, modern CRS designs have changed considerably to accommodate newer advanced features. This study looks to give a means of quantifying CRS geometry so vehicle and CRS manufacturers have access to accurate geometric envelopes thereby enhancing accuracy, fit and hence safety to the end consumer.

In the current study, digital reconstruction of 22 rear facing (RF) CRS was accomplished using the Microsoft Kinect for Windows v1.0 sensor and supplemented by 18 OEM drawings. 40 child seats were compiled to represent 72 rear facing CRS in the current US market (as of April 2014). Finite element (FE) models of the individual seats were generated and placed into seat back and seat-pan angles typical of the industry and overlapped to create "virtual surrogates." The virtual surrogate was made available to both vehicle and CRS manufacturers for virtual fitment evaluations in various vehicle environments. Based on both physical installations of select CRS and virtual evaluation, the surrogate was found to accurately depict the volume, fitment and interference of modern RF CRS.

INTRODUCTION

Safety considerations in automotive design and optimization are crucial for the risk reduction and protection of vehicle occupants. In the field of pediatric automotive safety, child seats are the leading technology in providing safety and restraint to child occupants in automotive vehicles. These seats, classified by Federal Motor Vehicle Safety Standard (FMVSS) No. 213 as "child restraint systems" (CRS), give parents and caregivers a plethora of makes and models providing optimum safety through the developmental periods of a child's life. The success of CRS at reducing injury in motor vehicle crashes hinges largely upon their proper installation as well as their interface with the vehicle seat. Unfortunately, despite the best efforts by parents and caregivers a staggering amount of CRS are found to be installed improperly. In a study supported by the National Highway Traffic Safety Administration (NHTSA), critical errors were identified in as many as 72.6% of all CRS installations on a case-by-case basis (Decina and Lococo, 2004). Common factors regarding this issue can be attributed to user installation and improper adhesion to CRS manufacturer installation instructions. In many cases it was found that loose harness straps between the child and the CRS as well as the CRS and the vehicle seat were to blame. However, another source of error can be found in the interface between the CRS geometry and the vehicle seat where improper fitment may occur. With the growing number of additional features, side impact protection and geometric changes implemented into CRS design, it is becoming more difficult to promote proper CRS installation and standardize a way to account for the changing CRS market geometry.

It is of vital importance for vehicle interior design to optimize occupant safety while allowing for aesthetics, comfort, and the addition of accessory demands such as those placed by CRS. To date there is no standardized way to account for CRS geometry in the vehicle interior and efforts to do so have been long since outdated. In 1999 the Society of Automotive Engineers' created standard SAE J1819 as a way to characterize CRS geometry by defining an accommodation fixture in which to install CRS and evaluate fitment. However, it does not take into account the modern CRS geometric envelope, the addition of rigid Lower Anchors and Tether for Children (LATCH) attachment points, nor additional modern features of many CRS. The only other commonly referenced model is FMVSS #225 which gives a sample child restraint fixture with LATCH for fitment evaluation purposes, but also does not represent the true market envelope. In the European market, the Economic Commission for Europe of the United Nations (UN/ECE) Regulation No. 44 and Regulation No. 16 together establish a way to define CRS geometry and classification but as of yet such a system does not exist in the U.S.

This study looks to correct the lack of accurate industry standardization and give a means of quantifying CRS geometry so vehicle and CRS manufacturers have access to true and current volumes thereby enhancing accuracy, fit and safety to the end consumer. This is accomplished by use of a computerized model, or "virtual surrogate," that captures the true geometry of the smallest rear-facing (RF) CRS. By combining novel CRS computational modeling with original equipment manufacturer (OEM) designs, an accurate model capable of being updated as the CRS market evolves can be developed.

METHODS

Scanning Methodology

This study makes use of Microsoft's Kinect for Windows v1.0 (Microsoft Corp. WA) for the purposes of converting real-world objects into virtual three-dimensional models. Microsoft's initial entry into the field of scanning technology began with release of the Kinect for the Xbox 360 with the intent of enhancing gamer experience. Mass appeal shortly followed the Kinect's powerful ability to scan real world objects with a relatively cheap market tag price. This prompted the release of a PC-specific adaptation for the purposes of independent development.

The Kinect v1.0 uses a scanning methodology based off of the principles of scattered light. Under these principles, the Kinect emits a pre-defined speckled pattern using an infrared emitter and detects the change and distortion in the pattern using a separate infrared depth sensor. These changes are read as the Kinect's depth of field and allow for reconstruction of the environment before it. Any areas where the scattered light pattern does not touch are interpolated and filled by the sensor. The active viewing field occupies a 43° vertical by 57° horizontal space. The Kinect also makes use of a 1280 x 960 RGB camera for color image capturing with both color and depth streaming capabilities that work at a rate of 30 frames per second (Microsoft Developer Network, 2014).

The process of CRS scanning begins by placing the CRS on a flat, level surface. Manufacturer's guidelines are used to simulate the proper positioning of individual CRS. The Kinect is then manually passed about the CRS, capturing geometry corresponding to all surfaces and components to give the most accurate image resolution possible. The CRS is then repositioned to separately scan areas not visible in the first pass; most commonly the bottom of the CRS. For CRS in which multiple configurations are possible, the CRS is scanned multiple times to account for these changes. It is important to note that some aspects of the Kinect can be temperamental and accommodations for it should occasionally be taken into account. Such accommodations include proper lighting allocation, proper space allocation and speed of scanning.

Images captured by the Kinect are converted in real-time to a three-dimensional shell by use of real-time scanning technology through ReconstructMe (PROFACTOR GmbH, Austria). The shell is then able to be imported into Hypermesh v12.0 (Altair Inc., MI) where they are post-processed for extraneous noise and objects that may have been picked up during the scanning process. Importing and combining multiple files is possible and often necessary to construct the complete CRS virtual shell. This model is then "shrink wrapped" using one of the program's tools to seal any gaps or holes and yield a flush shell surface. To ensure that multiple scans are seamlessly combined, the model is "shrink wrapped" to create a single solid surface. The process can b visualized in Figure 1. The virtual model is then translated to a standard virtual geometric origin at (0,0,0) on a three-dimensional virtual axis according to the SAEJ211 right-hand coordinate system. All CRS were positioned with the top facing in the positive z-direction and the front facing in the positive x-direction.

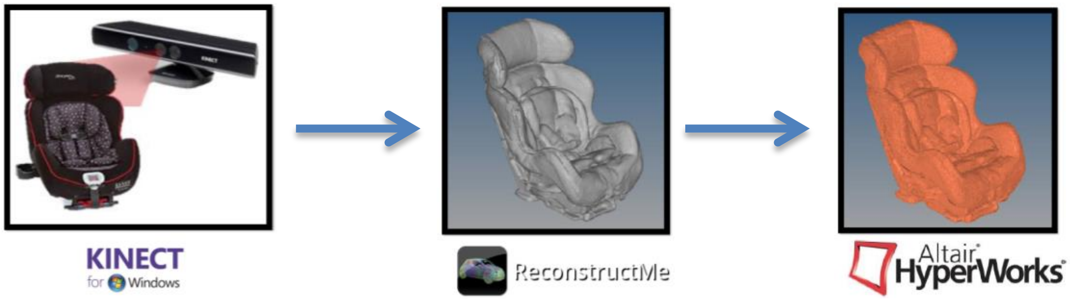

Figure 1: Virtual surrogate scanning process for a sample CRS.

For this study, 9 convertible seats, 12 rear facing infant seats, and one 4-in-1 seat were scanned and digitized for a total of 22 seats using the aforementioned methodology. An additional 18 OEM CRS (11 convertible seats, 5 rear facing seats, and two 3-in-1 seats) were included. In total, 40 individual models were used and representative of 72 CRS models in the US market as of April, 2013.

RESULTS / DISCUSSION

Smallest Virtual Surrogate Development

The development of the first virtual CRS surrogate focused on the selection of RF CRS. To establish the smallest RF surrogate, three RF-only CRS were identified to be the smallest market representations as of April 2013: the *Britax B-Safe*, *Safety 1st Comfy Carry, and Graco Snugride*. This identification was based upon their overall dimensions, virtual footprint (base included), and manufacturer installation guidelines. The virtual models developed from this selection were positioned at a standard vehicle seat angle of 13.5° and a seat back angle of 110° from the horizontal (Reed et al. 2004). After proper positioning, the virtual models were combined and "shrink wrapped" together to create the virtual surrogate (Figure 2).

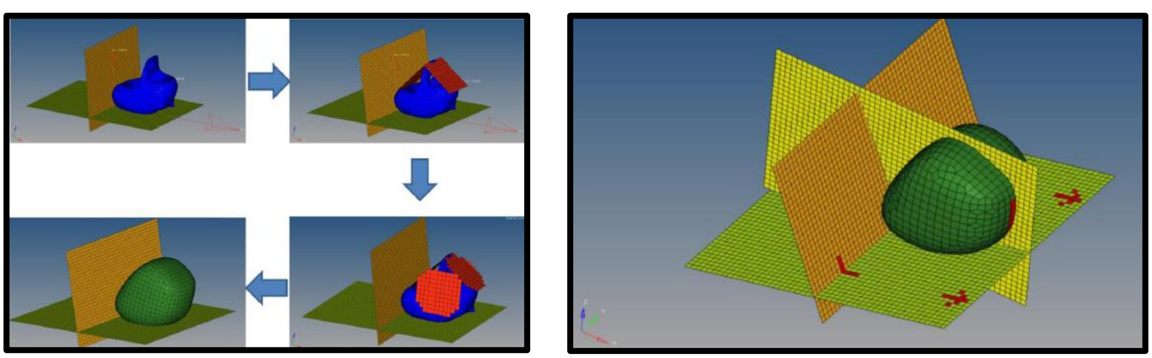

Figure 2: Development of the virtual surrogate (Let) and the final smallest RF surrogate (Right).

Virtual Surrogate Evaluation

Virtual fitment evaluations were carried out by members of the Center for Child Injury Prevention Studies (CChIPS) board of the Center for Injury Research and Prevention (CIRP) at the Children's Hospital of Philadelphia. FE models and surface data set (iges) files of the smallest RF virtual surrogate were supplied to the members for evaluation within a virtual sub-compact passenger car, a compact sedan, and a compact SUV (Figure 3). Both outboard and center rear-seating positions were surveyed with respect to various combinations of fore-aft positions of the front seat. Evaluation criteria were based on interference with the front seat, seating angle, and generic feedback regarding surrogate size and shape.

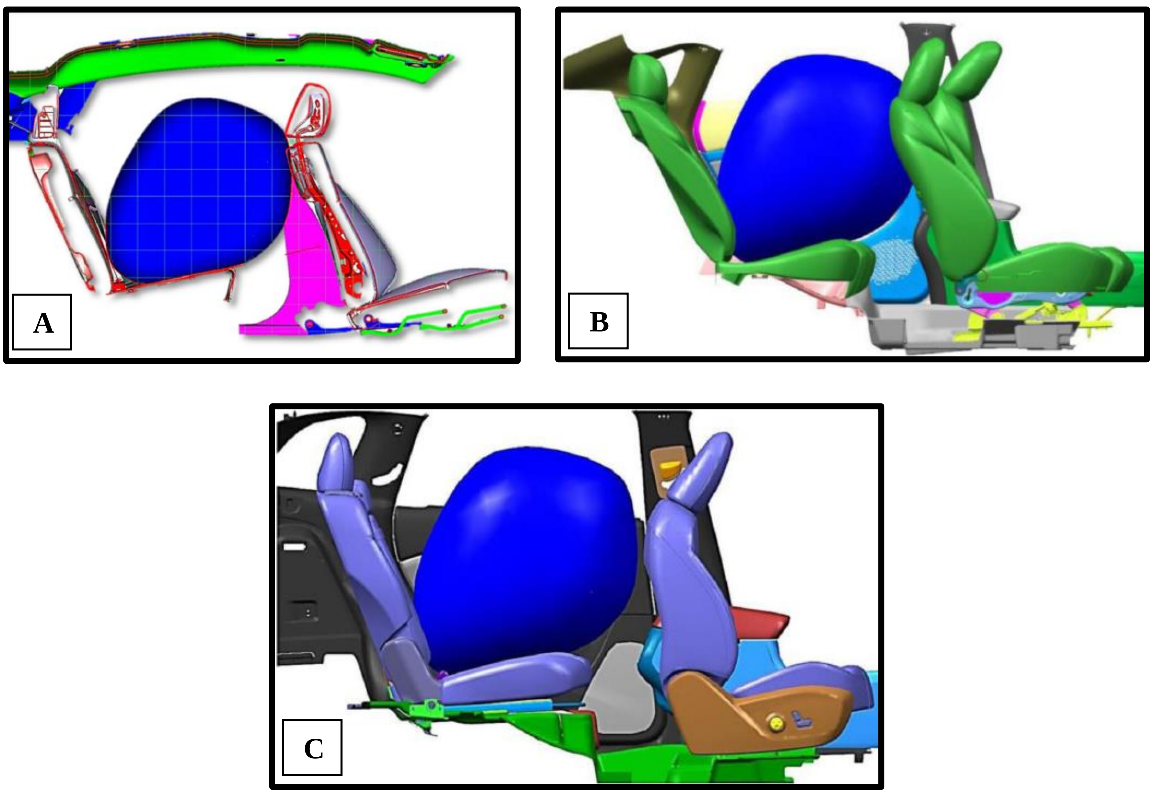

Figure 3: Virtual surrogate evaluation in the vehicle environments of a (A) sub-compact sedan, (B) compact passenger car, and (C) compact SUV.

Accuracy of the virtual surrogate was evaluated by physical installation of the three smallest RF CRS into real-world vehicle environments. Physical measurements were compared to the virtual fitment of the surrogate to test for its ability to predict CRS-vehicle compatibility and fitment. These assessments proved the accuracy of the virtual surrogate in correctly depicting CRS volume and simulating any interference.

CONCLUSIONS

In this study, geometric data was collected on 40 CRS (rear facing infant seats, convertible seats and combination seats) to represent over 72 CRS in the U.S. market as of April, 2014. Virtual models were created using a novel scanning methodology and combined with designs supplied by OEM to create an initial virtual surrogate for a specified vehicle seat pan and seat back angle. This surrogate represents the first attempt at providing a way to categorize CRS geometry for the smallest RF CRS available in the market using the three smallest identified RF seats.

Virtual fitment and evaluation tests were carried out by participating manufacturers of CChIPS in outboard and center-rear seating positions of a sub-compact passenger car, a compact sedan, and a compact SUV in various front seat fore-aft positions. Physical fitment evaluation tests were also carried out using the three identified RF seats to evaluate the predictive accuracy of the virtual surrogate. It was found that the virtual surrogate was capable of accurately predicting interference typical of installations of the identified smallest RF seats.

There were a few identifiable limitations of this study. The CRS models incorporated into the surrogate were limited solely to those available in the U.S. market. Additionally, the surrogate was tested virtually within an average seat back and seat-pan angle for which different seats in the spread of the vehicle seat market may yield different results.

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REFERENCES

Decina, Lawrence, and Kathy Lococo. "Misuse of Child Restraints." *U.S. Department of Transportation National Highway Traffic Safety Administration* (2004). Print.

“Kinect for Windows Sensor Components and Specifications.” *Microsoft Developer Network*, Accessed Sep 2014.

Reed, M., Ebert, S., and Carlson, M., “Development of Surrogate Child Restraints for Testing Occupant Sensing and Classification Systems,” SAE Technical Paper 2004-01-0843, 2004, doi:10.4271/2004-01-0843.