REVERSE ENGINEERING OF A TRANSIT BUS FOR F.E. CRASHWORTHINESS ASSESSMENT

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ABSTRACT

A reverse engineering process was used to develop a finite element (FE) model of a transit bus for the crashworthiness and impact analysis. The process involved disassembly and digitization of the bus components, building finite element meshes, and merging all parts into one, complete bus model. Before tear down process begun, a global coordinate system was established by marking reference points, and taking measurements with a portable coordinate measurement equipment. All structural components were identified, labeled and removed from the bus structure. Connections between all structural parts were identified. After disassembly, geometric entities as lines, points and curves were scanned for each component. The geometric data obtained was transformed to the MSC PATRAN pre-processor, where finite element grids were generated, modified and merged. Individual parts were assembled. FE model of the transit bus also includes data from mass and thickness measurements, and material properties obtained from laboratory tests conducted for selected material samples.

The transit bus model is still under development; it will be subsequently validated, modified and improved. Connections between vehicle components are modeled by merging nodes, applying node constraints and spot welds. Nonlinear, dynamic finite element analyses are performed using LS-DYNA, an explicit, 3-D, dynamic, nonlinear finite element code. Rollover, rear and side impacts of the complete bus model will be studied to evaluate crashworthiness of the bus structure and safety of passengers. The current results will be presented on the Symposium.

INTRODUCTION

Florida Department of Transportation acquires over 300 buses and vans for public transportation each year. A large part of this fleet is designated to transport disabled passengers, often in wheelchairs. Due to the unique safety requirements for these vehicles on one hand, and the lack of strict standards for crashworthiness evaluation, on the other, there is a need for an advanced study of structural integrity and dynamic behavior during accidents. These vehicles, and especially their body structures, may have mechanical properties, such as component connections or new composite materials, which make them more vulnerable to a specific damage. In extreme cases, this situation can result in more risk during accidents for disabled passengers who, in contrary, should require special care and additional protection.

The paper presents the first phase of the research conducted to evaluate the crashworthiness of transit buses through computer impact analysis (simulated, virtual crash-testing). It illustrates a process of building a finite element model for a Ford Eldorado Aerotech 240 transit bus (see Figure 6). Because of potential liability, motor vehicle manufactures are reluctant to share their proprietary FE models with universities and other roadside research organizations. Since design data was not available for the bus selected by research sponsors, the reverse engineering was performed in order to create a reliable FE model. The process required vehicle teardown and digitizing of all major, structural parts of the bus.

A typical engineering process begins with an engineering concept, which often follows with an analysis and design. Desirable material properties are studied and selected materials are used for part production. Finally, all required parts are assembled in a final product or a system.

Reverse engineering proceeds in the opposite direction. It begins with a final product, which is disassembled into individual parts. The parts are taped, scanned, digitized, and mapped into computers for further analysis of the entire design and manufacturing process. Reverse engineering assists engineers in further improvement of their product. Here, the process involves disassembly and digitization of the bus components, creating finite element meshes, and merging parts into a complete bus model. Although nowadays the manufacturing process is frequently aided with computers to reduce possible errors, the final product is not always free of flaws, which could be introduced at any stage of the engineering process. A reverse engineering process is therefore needed to: identify all potential problems in all stages of the product manufacturing process, and assess an impact of different engineering options/design and manufacturing imperfections on the performance of the final product.

It is expected that the final computer model of the Eldorado Aerotech transit bus may consist of 50,000 to 100,000 finite elements. In addition to the size of the model, the crashworthiness studies require using non-linear, 3-D, explicit, dynamic, finite element codes capable of handling contact-impact problems with high-strain rate and non-linear, large deformations including plastic deformation and failure. The model developed will be used in the future to evaluate safety of different buses during accidents of various types including side- and rear- impacts, and rollover incidents.

TOOLS AND TECHNOLOGY

Since design data was not available for the selected bus, an actual vehicle was used to acquire geometric data needed to create a virtual model. The process applied in this study is commonly used in crashworthiness research community [1], [5] for passenger vehicles. It involves disassembly and digitization of the vehicle components, creating finite element meshes and merging parts into a complete bus model. A portable measurement device called a digitizing arm [3], presented in Figure 1, was used to collect most of geometric data. The equipment allows for mapping complex geometrical entities such as 3D curves and surfaces into AutoCAD computer format. This device consists of three arms with rotary transducers in each joint. The signals from transducers are sent to the computer, which determinates the position of the probe tip end in x-y-z coordinate system. The device and the software AnthroCAM used to operate it, allow for digitizing of points, scanning curves and construction of such geometric entities as poly-lines.

Figure 1 – Portable digitizing device: FARO Arm

Geometric data obtained using FARO arm is exported in format of IGES files, which are transferred to PATRAN pre-processor [4]. The finite element model is developed in PATRAN and input files dedicated to LS -DYNA are created. LS-DYNA is an explicit finite element code for analyzing 3-D, non-linear, large deformation, dynamic response [5]. Extensive library of material models, multipoint constraint and spot weld options, and contact-impact algorithms allow for efficient analysis of contact-impact problems with failure.

Figures 2 through 5 show an example of a reverse engineering process starting with digitizing (Figure 2) and completed with computer simulation (Figure 5). A segment of a front bumper of the transit bus, presented in Figure 2, was selected as an illustrative example. Figure 2 shows tapes marking curves on the actual bumper, which were scanned using digitizing arm. Resulting poly-lines are presented in Figure 3. Figure 4 shows finite element model created using quadrilateral FE shell elements. Fully integrated shell element with 5 Gauss integration points through the thickness was applied. Bilinear elastic – plastic material model with properties for steel was used. Figure 5 presents results for computer simulation of a high velocity impact of the bumper with a rigid wall. Figure 5 shows contours of von Misses effective stresses induced during the contact with a rigid wall (legend of stress fringes remains invisible in picture).

Presented simple example illustrates the reverse engineering procedure of building a finite element model. Computer simulation obtained using LS-DYNA program provides numerical data including time histories of displacements, velocities and accelerations for selected points. Contours of strains and stresses can be plotted to assess structural integrity of the system as a function of time during impact.

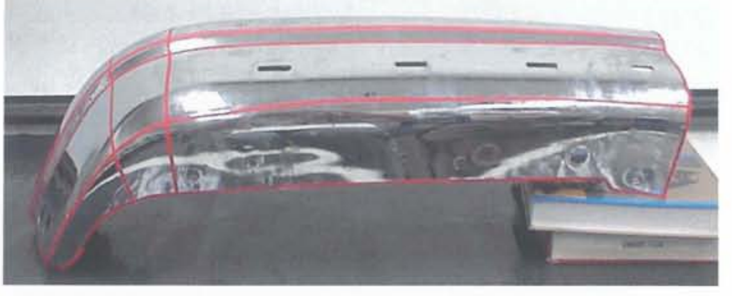

Figure 2 – Segment of a transit bus bumper with tapes marking curves for digitizing.

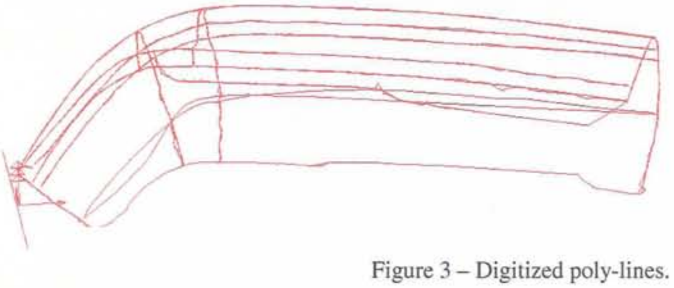

Figure 3 – Digitized poly-lines.

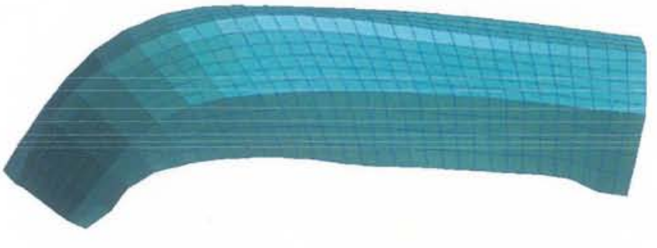

Figure 4 – Finite element model.

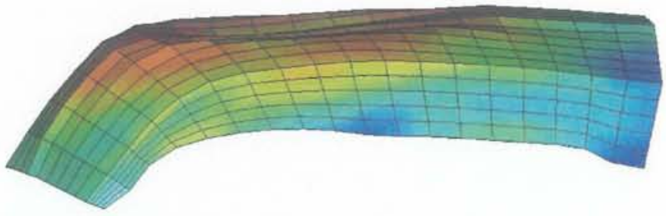

Figure 5 – Contours of von Misses effective stresses.

DIGITIZING AND DISASSEMBLING OF FORD ELDORADO BUS

The User Coordinate System (UCS) should be determined at the beginning of the geometric data acquisition, before taking any measurements. The User Coordinate System set up for the bus is presented in Figure 6. It was established by digitizing a set of 240 reference points marked with labels on the bus body (see Figure 6). Figure 7 shows computer image (top view) of digitized reference points and device positions. Reference points are used (after error distribution) to determine a current position of the digitizing arm. Since Faro Arm is relatively small comparing to the bus structure, the device had to be moved around the bus from one location to another. The first set of reference points was also used to digitize additional points marked on all structural parts before their removal. The total number of reference points exceeded 700.

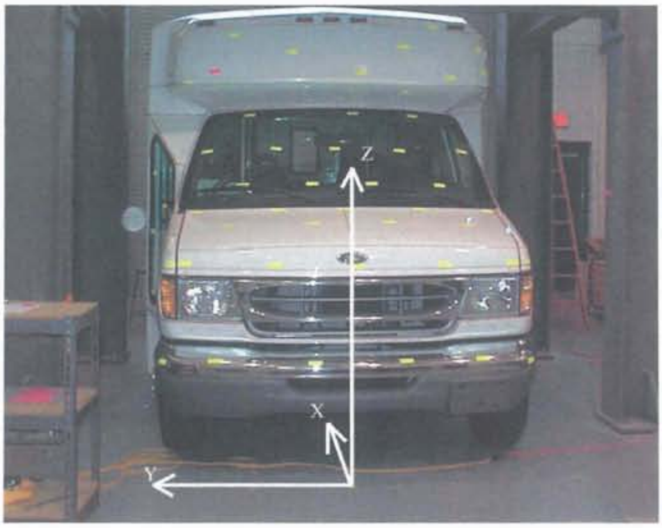

Figure 6 – User Coordinate System established for Eldorado Aerotech transit bus.

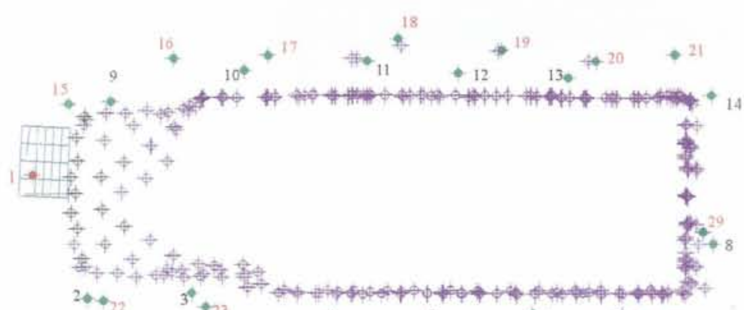

Figure 7 – Computer image of reference points and 29 device positions (top view).

The model development requires vehicle teardown and digitizing of all major, structural parts of the bus. All structural components were identified, labeled and removed from the bus structure. Figure 8 shows disassembled bus structure. At least three reference points were digitized for each part before its removal to determine the component position in the global coordinate system. Connections between structural components were identified. After disassembly, geometric entities like lines and curves were scanned for each component. Geometric data obtained was transferred to MSC PATRAN, where finite element grids were generated, modified and merged. An interim set of the geometric quantities, obtained for exterior bus surface, is depicted in figure 9. Digitizing part of the research resulted in data acquisition of major geometric quantities including reference points and poly-lines, which are mapped into the computer model.

Geometric data is subsequently used as an input for building finite element meshes. Figure 10 presents a process of building finite element grids using digitized poly-lines, shown earlier in Figure 9. Development of finite element grids for some bus components is presented in Figure 11. Finite element (FE) model will include data received from mass and thickness measurements and material properties obtained from destructive strength tests

Figure 8. Disassembled Ford Eldorado Aerotech 240 transit bus.

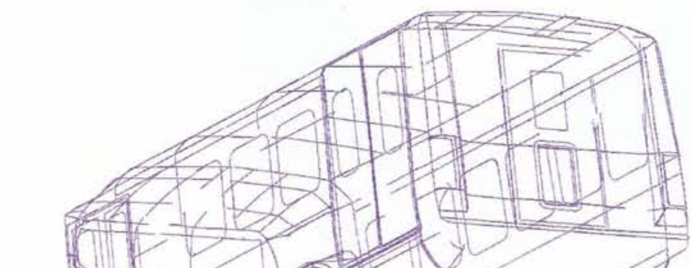

Figure 9. Polylines scanned for exterior bus components.

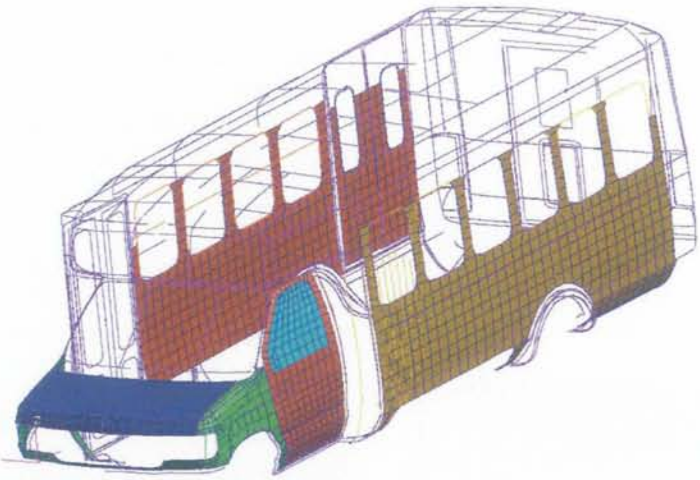

Figure 10. Development of finite element meshes.

performed for several material samples. The first validation step of the model will be based on the weight comparison between FE models and the parts that they represent. The parts are to be merged using pre-processors. Connections between vehicle components will be modeled by: merging nodes, applying constraints and spot welds. Inertia property testing will be performed for the actual bus using a tilt table technique. This data is used to validate mass distribution for the whole model, its center of gravity, and moments of inertia. Several preliminary tasks will be performed, including static and dynamic testing of structural samples, and testing and improving of the methodology for data acquisition.

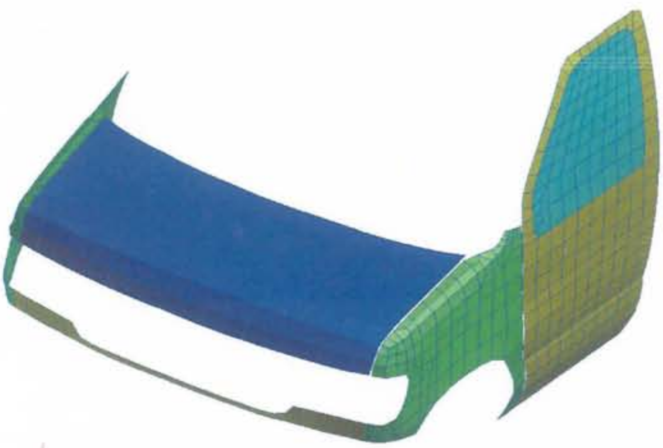

Figure 11. Finite element meshes for some of hood, fenders and driver door.

Nonlinear, dynamic finite element analysis is performed using LS-DYNA, an explicit finite element code. After model validation phase is completed, rear and side impacts are planned to be simulated to evaluate safety and integrity of the bus structure.

It is expected that this cutting-edge technology will assist engineers in designing safer and more economical transit buses. Subsequently, research results from this study will help improving safety standards for transit buses.

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