New England
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Year 25 Final Report

Grant Number: DTRT13-G-UTC31

Project Title:

An Innovative Design to Retrofit Seatbelts in Motorcoaches

Project Number:	Project End Date:	Submission Date:
UMAR25-29	1/31/18	3/26/18

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Problem:

Prevention of passenger ejection from motor coach seats in the case of rollover and frontal crashes is critical for minimizing fatalities and injuries. This project proposed a novel concept of affordably retrofitting 3-point seatbelts to protect passengers during these significant crash scenarios. Prior to this project, the available options involved replacement of either the entire fleet, which takes time to avoid extremely high costs, or all seats with new seats that have seatbelts, which is still expensive.

Approach:

Alternatively, this project developed of an innovative product that can be installed in seat belt-ready bus structures at a fraction of the cost. The efficacy of the design was studied using finite element analysis (FEA) to meet Federal Motor Vehicle Safety Standards (FMVSS) 210 standards for conditions involved in frontal and side impacts. Similarly, the design's effectiveness in rollover scenarios was studied using dynamic loading conditions in MAthematical DYnamic MOdeling (MADYMO) simulation software. The results from FEA and dynamic simulation studies were subsequently utilized to optimize the design for safety and comfort, as well as ease of maintenance and cleaning. The many salient features of the design include an optimized shape to maximize leg comfort and conformance to and clearance with many various seat configurations; a sliding guide on the shoulder belt webbing to accommodate different heights of the passengers; a provision for padded damping to enable rear occupant protection along with belt retractor enclosure; and optimal location of anchor points close to the seat to enable easy buckling of seatbelts and prevent slacking of seat belts during any crash. The following results of this work published in an SAE conference paper as follows [1].

Background

The world population is on the rise, and owing to limited geographical area, the strain on means of travel is increasing. As roadways have become the most preferred means of travel, the ever increasing number of vehicles on existing roads is increasing the risk of accidents. Thus the motor coach industry in the world today is faced with the widely acknowledged challenge to protect and ensure the safety of their passengers. A typical motor coach carries 55 occupants, and has a gross vehicle weight of 22,680 kilograms [2], making the consequences of a crash even more severe than crashes involving passenger cars. Owing to the high occupancy rate of motor coach buses, buses involved in fatal crashes affect many lives and are thus the very reason for the rise of several Congressional and activist groups in the United States. These activist groups are highlighting the need for improvement in the safety of travel in motor coaches, particularly the availability of seat belts. Thus the motor coach industry is facing potential upheaval due to efforts of these several interest groups that are unsatisfied with the safety of travel mandated by federal safety codes, and for good reason: in 2014 alone 234 motor coaches were involved in fatal crashes in the United States [3]. The statistics regarding seatbelt use [4,5] have been particularly useful in accentuating one area in which the motor coach industry is lacking: availability of seat belts. It has been shown that the use of either a two-point lap belt or a three-point seatbelt greatly increases the likelihood that occupants will remain in their seat during a collision [6]. This not only prevents their bodies from moving freely inside the vehicle and causing injuries but also prevents complete ejection from the vehicle, which is important during frontal collisions and rollovers (the two most common types of bus collisions) [7]. Overall, ejections account for 45% of all fatalities in motor coach crashes and 66% in rollovers [8].

Furthermore, estimates indicate that seatbelts are 77% percent effective in preventing fatalities in rollover crashes [7].

As of 2013 only 11%[1] of motor coaches in the US were equipped with seatbelts. In its 2013 ruling [9], the United States Government traffic safety body: National Highway Traffic Safety Administration (NHTSA) finally made it mandatory for buses manufactured by 2016 to be equipped with three-point lap and shoulder belts for all seats. Though this regulatory mandate for equipment of seatbelts on newer motor coach buses makes them safer, no regulation has been issued for currently on-road older motor coaches. Furthermore, the average life of motor coaches is expected to be more than 20 years [10] with older motor coaches being used longer by small operators as they are resold, thereby putting a lot of passenger lives at risk of accidental deaths for a longer period of time. Thus, installation of seatbelts on these on-road motor coaches is necessary to reduce this risk associated with passenger ejection and other crash scenarios.

NHTSA, in its notice for proposed rulemaking and retrofit assessment [9,10], cited the cost of installation as a major hindrance for installation of seat belts on older motor coaches. The estimated cost to replace older seats with newer seats was considered in their report. The results of a pertinent patent search were broadly classified into three main categories. These patents, such as identified examples of each category [11-13], were further analyzed for their applicability and their effective cost which formed the rationale for development of the seatbelt retrofit product described in the following section. To address these needs, a novel idea of retrofitting seat belts on existing motor coaches was proposed [14]. Figure 1 shows the patent-pending seatbelt retrofit concept.

Figure 1: Seatbelt retrofit design [14]

This final report highlights the further development of this concept. The design section in this paper addresses the essential criterion considered in the development of this patent-pending design and its further improvements. Since reduction in the total installation cost has been the critical factor bolstering the development of this new product; critical aspects affecting the

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[1] NHTSA estimates number of buses requiring retrofit as 29325 as per their published report [5]. The number of buses on roads as of 2013 is 32825 [8].

overall cost like material, manufacturing, machining, assembly and installation were taken into consideration and addressed in the design section. Furthermore, cost estimates from NHTSA [8] were used as a benchmark for analysis of the seatbelt retrofit product's affordability and are compared in the cost analysis section. Additionally, the product needs to meet the required safety standards for impact loading during crashes. Thus US Federal Motor Vehicle Safety Standards (FMVSS) standards are used to determine the effectiveness of the seatbelt retrofit product in head on collisions. The loading conditions for static analysis were derived from the FMVSS 210 standard [15]. This static analysis section presents the associated FEA simulation results. Additionally, efficacy of the product during rollover crash scenarios was simulated. Here, MAthematical DYnamic MOdeling (MADYMO) software was customized and used to simulate a rollover crash with the retrofit product installed in a motor coach model. The section on dynamic analysis further explains this study setup and its outcomes. Overall, the results of the dynamic and static analysis guided the product design and its other attributes and were further utilized for improving the product with other potential benefits.

Although affordability and efficacy are obvious minimal requirements, numerous other criteria should be considered and thus the Ergonomics/Aesthetics section highlights such enhancements. Potential areas of improvement were studied and are discussed in the optimization section. Finally, the paper concludes with an overall summary of the work done and benefits of the design. The following section first introduces the rationale for design of a seatbelt retrofit product.

Design Rationale

Although passenger restraint systems, airbags and compartmentalization have been implemented in smaller passenger vehicles; large capacity older motor coaches have still been left out due to the cost associated with the installation of the same. A patent search [11-13] revealed three categories: a seat belt system that assembles onto an existing seat structure, seatbelt systems designed for highly specialized vehicle configurations and replacement of the entire seat with a newer seatbelt-fitted seat system. Thus the first category of seat belts patents was limited in application owing to majority of the seat structures not designed for seatbelt loading. The second category of patents being highly specific in configuration was thus ineffective for use in motor coaches where the variation in seat configurations is significant. The third alternative was already analyzed by NHTSA in their assessment for retrofits [8] and found to be too expensive for any widespread adoption. Thus this patent search indicates a need for a more adaptable and affordable product. The development of a new product involved consideration of various different features which are covered in the next section.

Design

Toward the most universally adaptable solution, this retrofit installation concept bolts to an existing floor railing to utilize existing bus structure integrity and facilitate installation. The offset of the rail location from the center of seat pairs varies among makes of motorcoaches. Variation in the height of the seats was also accounted for in design. Other potential clearance obstacles include different attachments on existing bus seats such as recliner pneumatics and foot rests.

To consider maximum structural integrity and resulting occupant protection, the head and neck injury values from NHTSA's crash tests [16] studies bolstered the decision to select the three-point lap and shoulder belt instead of a mere two-point lap belt only design. During the benchmark head on collision scenario [15], the majority of forces act in a forward direction thus leading to selection of an "I-beam" cross-section for the post structure.

Figure 2 shows a 3D CAD rendering of the product with a vertical post structure providing the shoulder and retractor anchor points and the structure with curvilinear arms serving as the anchor supports for the buckle anchor points. This anchor support includes a base-plate mountable onto the floor. Additionally, the use of side railing was implemented in design to further strengthen the structure's rigidity as well as to allow for weight reduction on the window side arm of the anchor support part. With the critical goal of minimal material usage and low cost, design of variable cross-section is optimized along the length of the post structure. Thus, a casting process was selected as the manufacturing process to allow for variability in cross-section as well as manufacturability of complex geometry.

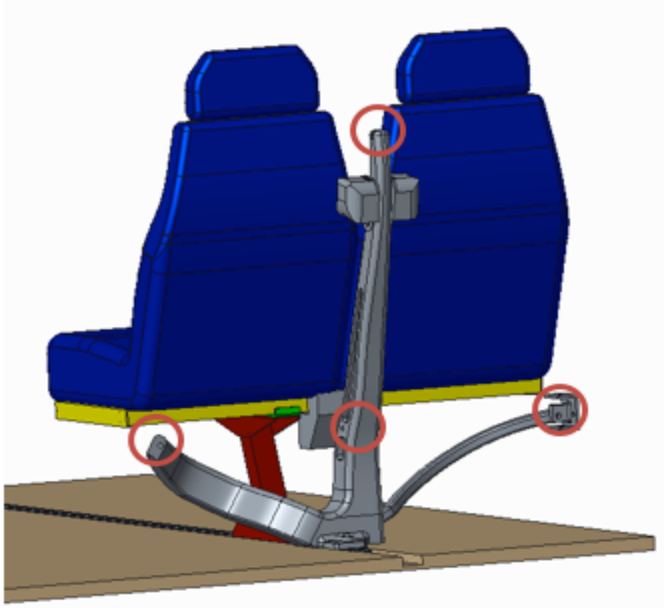


Figure 2: Seatbelt retrofit product assembly (anchor points circled)

Further the design process involved determination of the applicable loads to withstand, so these loads were obtained from the FMVSS 210 standard [15]. This standard requires that body blocks in the lap and shoulder belts withstand a force of 13345 N each simultaneously. Thus engineering statics was deployed to determine the resulting forces at each anchor point and the floor railing and its mounting T-bolts. With the implementation of a product design involving metal structures, the impact of additional weight in each bus was assessed.

Table 1: Weight capacity analysis of the motor coach

Bus size	GVWR (kg)	Unloaded weight (kg)	Loading capacity	Approx. Loaded weight (kg)	Extra capacity (kg)
14 m	20,593	14,787	54	19,781	892
12 m	18,960	14,424	46	18,610	350

The weight assessment in Table 1 was done on two different sizes of motor coaches. The gross vehicle weight rating (GVWR), or maximum allowable weight for a vehicle that is full, is found in a NHTSA report [17]. The GVWR of these motor coaches was 20,593 kg and 18,960 kg with empty buses weighing 14,787 kg and 14,424 kg, respectively. Average passenger loading of 91 kg per person including the luggage was taken into account combined with all of the retrofit structures in order to determine the total weight of a full bus. Thus the weight analysis shows sufficient weight capacity of 892 kg and 350 kg in 14 m and 12 m length buses, respectively. This indicates that no reduction is seating capacity on any bus should be necessary.

Affordability/ Cost analysis

One current option to add seatbelts available to bus operators may be the replacement of their entire fleet with newer motor coaches that have seatbelts. In reality, this would take time for any bus operation to convert completely given the cost of newer motor coaches. The other current alternative involves replacement of the older seats with newer seats fitted with seatbelts, which is an expensive option for an older bus. NHTSA estimated a cost for this option at approximately $40,000 per motor coach [9]. This cost was deemed infeasible by NHTSA for smaller motor coach operations. Cost of the retrofit design depends upon factors such as material, manufacturing time and process, installation time, seating capacity, and weight added in the vehicle.

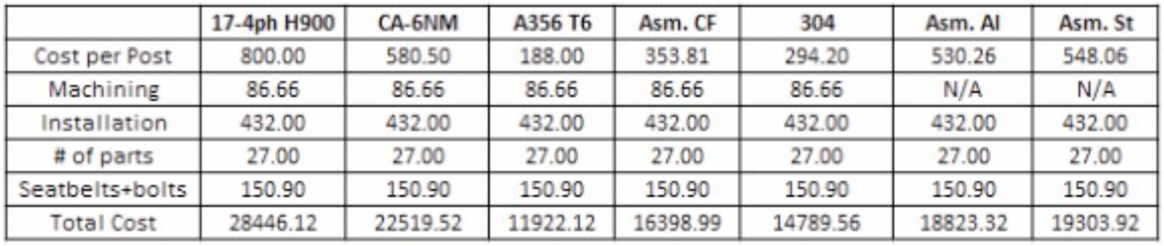
Commonly available grades of steel and aluminum alloys were considered for comparison of costs associated with raw material and manufacturing process. Quotations were obtained from some capable casting foundries in the US. Table 2 below shows the approximate cost estimates among several alternatives in USD. The cost of machining and installation were assumed to be same for all these different materials. Additionally, the labor cost for installation of the product with different materials would be nearly the same. In addition to casted products, alternatives of cutting and welding to assemble steel or aluminum, along with an assembled lay up of carbon fiber (CF) were all considered and are shown in columns in Table 2.

Based on the cost differences, aluminum A-356-T6 was selected as the material for casting of the product. The foundries advised that the cost estimates will vary close to linearly with weight variations given the same material. Thus, minimization of the solid volume or weight of the part geometry has added design significance. It is assumed that the fixed costs associated with casting processes, such as tooling can be sufficiently amortized by economies of scale, given the number of buses without seatbelts. All of these cost estimates presume that the part will also be sufficiently strong to meet the demands of all crash scenarios. The next section discusses further the static analysis used for optimization of the design to meet those strength requirements.

Static Analysis

The design structure must withstand the static loading based on conditions as discussed in the design section. Additionally, a need for structural assessment of the bus structure involving floor railing and its attachment hardware was determined. Thus, this static analysis has been divided into two major sub-sections. The following sub-section analyzes the bus floor structure along with the mounting hardware. This is followed by a sub-section that assesses the crashworthiness of the product structure itself.

Table 2: Cost analysis of alternative materials



	17-4ph H900	CA-6NM	A356 T6	Asm. CF	304	Asm. Al	Asm. St
Cost per Post	800.00	580.50	188.00	353.81	294.20	530.26	548.06
Machining	86.66	86.66	86.66	86.66	86.66	N/A	N/A
Installation	432.00	432.00	432.00	432.00	432.00	432.00	432.00
# of parts	27.00	27.00	27.00	27.00	27.00	27.00	27.00
Seatbelts+bolts	150.90	150.90	150.90	150.90	150.90	150.90	150.90
Total Cost	28446.12	22519.52	11922.12	16398.99	14789.56	18823.32	19303.92

Bus Floor Assessment

Engineering calculations were done on an initial design [14] with a bolting span length of 0.18 m. The assumptions of this analysis were simplification of the model of the base-plate as a hinged beam at one end and simply supported beam at other end, which was used to determine the required pretension on the T-bolts. The required pretension of bolts was calculated to be 34,812 N while accommodating for different uncertainties in pretension loading and using a frictional coefficient of 0.23 between the two surfaces of contact. 12 mm diameter bolts with washers were assumed in the calculations.

A corresponding setup for FEA in ANSYS Workbench consisted of a fixed support applied to the bottom of the floor railing as it is welded in places onto the bus structural frame. Since bus structures vary widely by design and age and condition, the modeling assumption in this case was fixed support on the entire bottom of the rail for simplicity. Thus, each individual bus structure should be assessed on a case by case basis. In this model, the interactions between the bolts and the other parts were modelled as bonded contacts for faster computation. Additionally, a frictionless contact was modelled between the bolt and the product in the axial direction. The conservative pretension loading of 34,812 N was applied to each of the individual bolts. The FEA simulation results are seen in Figure 3 and 4. The maximum stress found on both the bolts and the rail is within an imposed limit of 630 MPa. That limit was based on the strength of these bolts and the railing obtained from a crash report by NHTSA [18] specified as 903-930 MPa (131-135 ksi) for the T-bolts and 861 MPa (125 ksi) for the floor railing. Figure 3 shows a maximum stress of 593 MPa (86 ksi) to be acting on the T-bolts which has an equivalent factor of safety (FOS) of 1.52. Thus the T-bolts shall withstand the loading.

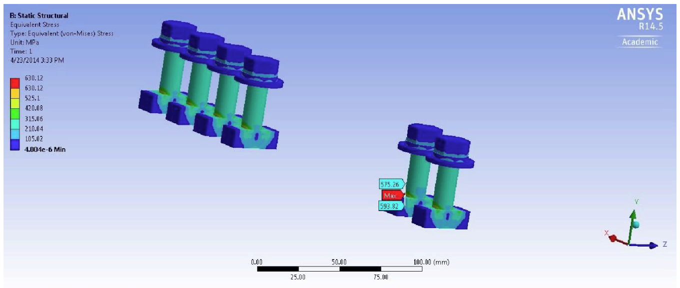


Figure 3: FEA for the bolts with 34,812 N pretension loading

Similarly, a maximum stress of 630 MPa (92 ksi) was observed in FEA of the railing equivalent to a FOS 1.37. Thus it was concluded that the bus structure with these floor railings meets the required specifications for retrofitting of seatbelts using this product [14].

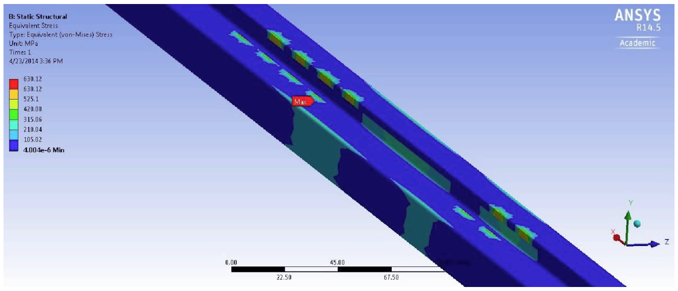


Figure 4: FEA for the floor railing

Additionally, a study of the variation in the strength of the floor railing, based on data obtained during an extrusion process, was done which resulted in estimated standard deviations of 12.89 MPa (1.87 ksi) for strength reduction during an extrusion process and 19.1 MPa (2.77 ksi) for additional stresses induced. Thus the maximum allowable stress for floor railing was determined to be 767.4 MPa (111.3 ksi), which is three standard deviations from the mean strength even if the worst extrusion and loading uncertainties occur simultaneously.

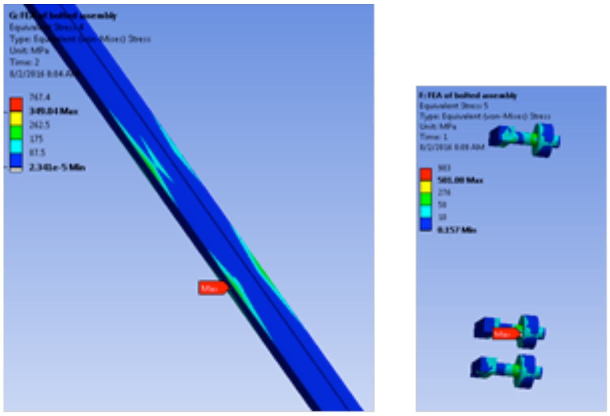


Figure 5: FEA of railing and bolts with updated design

Thus, the maximum allowable stress based on probability exceeds the maximum resulting stress on the railing seen in Figure 4. The factor of safety on the bolts is greater than that of the rail. Further assessments were done for reduction of the uncertainties in pretension loading as well as loading conditions in part by utilizing the additional mount of the side railing of the bus, thus allowing for reduction in the required number of bolts. Figure 5 shows the FEA results of the railing and T-bolts with current design and loading conditions. The FOS of the railing is 2.1 and that of the bolts was found to be 1.8. Thus, the bus structure can be safely used without requiring additional reinforcements provided that the bus structure under the rail is also sufficient for these loads on a given bus. The next sub-section discusses the product structural analysis.

Product Structure Assessment

The product structure assessment is further divided into subsections of material properties, loading conditions and the modeling assumptions, concluding with the results. Figure 6 shows the FEA of the original design. As seen in the figure, the maximum stresses were 638 MPa (92.5 ksi) which is significantly higher than the allowable stress limitation of 138 MPa (20 ksi) as determined in the material subsection. However, this study was useful to verify geometry optimization for uniform levels of stress along the entire length of the post.

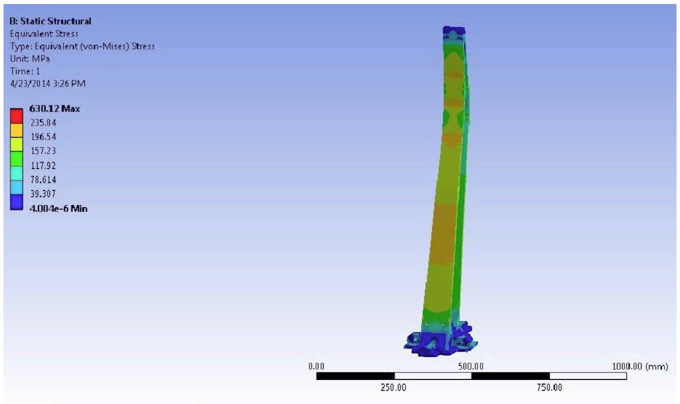


Figure 6: FEA analysis of original patent-pending design [14]

Table 3: Components of force at different anchor points

Components of force	X (N)	Y (N)	Z (N)	Resultant (N)
Lap belt anchor point	6672	1320	4508	8160
Shoulder belt anchor point	6672	2390	4043	8160
lap and shoulder belt buckle anchor point	13345	3716	8552	16280

Material

Aluminum A-356 was the material chosen for casting of the product based on its lightweight, high strength, and the overall low cost estimates. As this alloy is a premium casting material, it has thus better strength than 356 alloy. The mean strength of this alloy is specified at 282.7 MPa (41 ksi) [19]. Associated data specifies a standard deviation in strength of 13.8 MPa (2 ksi) [19]. Thus, for a reliability of 3σ, the lowest probable strength was found to be 241.3 MPa (35 ksi). Empirical data of stress concentrations caused by porosity [20] indicate a standard deviation of 34.5 MPa (5 ksi) for such stresses. Estimates that combine these effects with data that accounts for any residual stresses in A-356 castings [21] were used to determine the resultant allowable stress of 138 MPa (20ksi). To corroborate this calculation, the Federal Aviation Association (FAA) [22] specifies the use of casting factor of 2 for critical structural castings, which results in the same allowable stress of 138 MPa (20 ksi).

Loading Conditions

A series of crash test and static sled tests were conducted by NHTSA, the results of which were further utilized for amendment of safety standards for seat belts and their supporting structures [16]. As a result, FMVSS 210 [15] requires the application of 13345 N (3000 lbf) force on a lap belt and shoulder belt simultaneously. Engineering statics can model such loading to determine the resulting forces acting on each anchor point of a structure. The modeling assumptions here include the lap and shoulder belt at a buckle acting as a frictionless pulley system allowing for equilibrium of tension in both belts. Another assumption utilized spatial locations for the dimensions of NHTSA's test equipment [15] to determine the angles of the resultant pulling forces at the anchor points. Thus the resultant force estimates of 8160 N on lap belt anchor, of 8160 N on shoulder belt anchor and 16280 N on lap and shoulder belt buckling anchor point were found for a single seatbelt system. The components of force can be found in Table 3 and the free body diagram is shown in Figure 7.

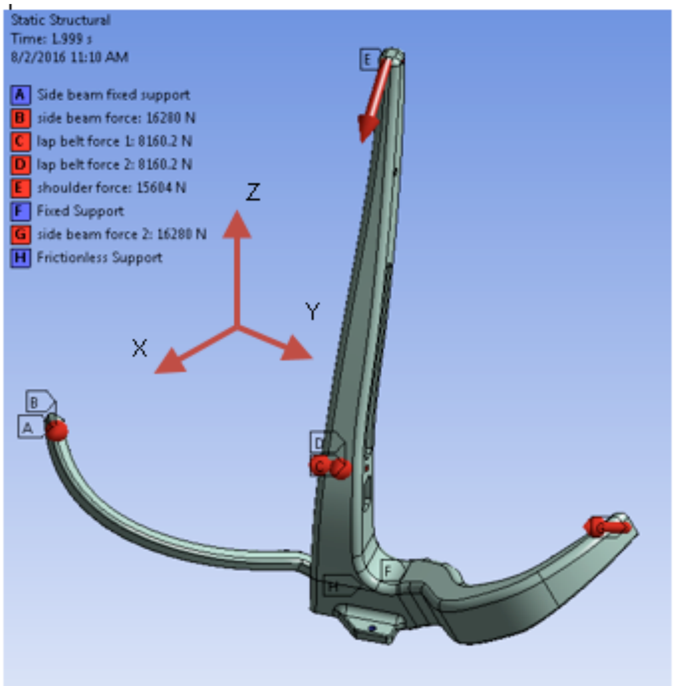


Figure 7 ANSYS Workbench setup with resultant forces at different anchor points

Simulation Set Up

The loads determined in the previous section were applied to the respective anchor points as seen in figure 7. All the simulations were done in ANSYS version 16.2 running on Intel Xeon E5-1620 v2, 3.70 GHz processor. A design assumption of casting the product as one piece was made. Furthermore, in order to reduce the overall computational time, the contact areas of the bolts with floor rail were applied bonded boundary conditions with the assumption of the bolts being effective in resisting the motion. For confirmation of the assembly efficacy, a separate simulation was done with frictionless contact between the floor rail and the bolts. The FEA simulation converged to the results shown in Figure 8. The stresses were found to be within the allowable stress limit of the material and the maximum deformation of 20 mm was observed.

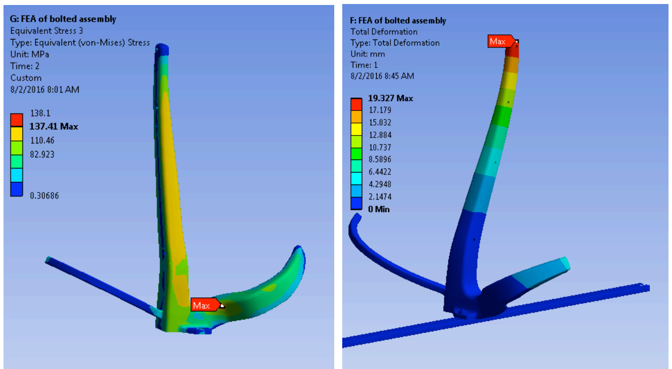


Figure 8 ANSYS results of the updated post structure design showing maximum stress (left) and maximum deformation (right)

Results of Simulation

The resulting post structure was thus found to meet the strength requirements and was been designed with additional inputs from the outcomes of dynamic analysis as well as ergonomic design decisions as seen in further sections of this paper. Overall a deformation of 20 mm is within permissible limits and thus indicates the product being safe for use. Although the product design did meet the strength requirements, there is still some potential scope for optimization which shall be discussed in the optimization section. The next section discusses the efficacy of initial product design in a dynamic rollover scenario.

Dynamic Analysis

Mathematical Dynamic Modelling (MADYMO), a simulation software tool for analysis of automotive crash safety, developed by Netherlands Organization for Applied Scientific Research, was used. This software allows multi-body dynamic simulation and thus was used to simulate the motion of belted passengers in this study. As a rollover crash involves passenger ejection, an actual crash report was used to test the effectiveness of the product.

Methodology

This simulation method involves modelling of the vehicle to be tested and data inputs of a known crash. A 2004 rollover crash in Arkansas ejected virtually all passengers, leading to 13 fatalities out of 29 injuries. Crash reports from Arkansas State Police Collision Report 181004369 and NTSB were acquired and used along with the PC- Crash Motion File.

MADYMO Analysis

The vehicle kinematics was defined by prescribing the motion for all degrees of freedom of a free joint as modeled at the approximate center of gravity (CG) of the bus. The orientations and joint positions were calculated using the crash reconstruction data generated by PC-Crash. The Euler parameters were calculated using orientation data generated by PC-Crash analysis. MADYMO version 7.5 developed by TASS, running on Intel Core i7-2600 3.40GHz processor was used for this simulation. This set up is shown in Figures 9 and 10.

Model Overview / Loading

The computational model consisted of an ellipsoidal bus model. The seats were loaded with Hybrid III 50th percentile ATD’s (Anthropometric Test Device) to simulate right side and left side occupants, Strategic positioning of passengers in the model was done to simulate all seating position and was based on the CG of the bus. A finite element belt model was attached to the anchor points of the initial product concept to model the seatbelt for simulation. Bus dimensions for the modelling were obtained from the crash investigation reports. As the far side passengers are at higher risk due to higher rotational distance, the simulation was conducted with this worst case loading of passengers seated at the far side. A friction coefficient of 0.3 was modelled between the occupant and the seat cushion foam, as well as between belt and the ATD. The Finite Element (FE) model of the belt simulates the realistic slide beneath the webbing during lateral motion of the ATD on the seat. The seat was modelled from a sample model obtained from a representative supply source in the United States.

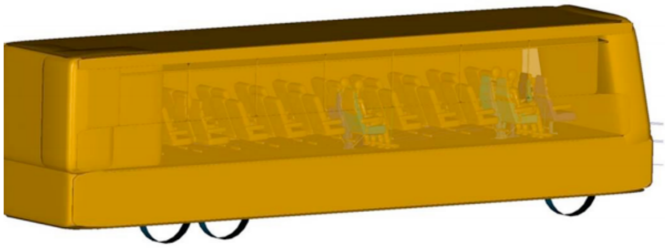


Figure 9 ATD position in the bus.

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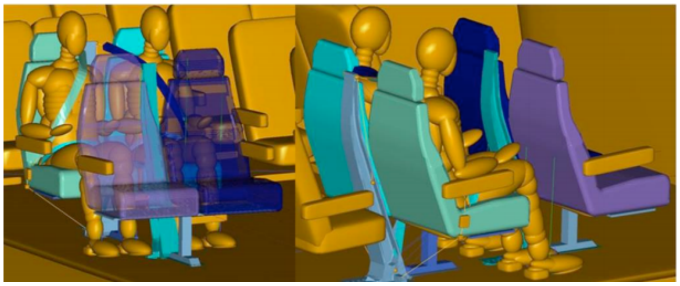

Figure 10 Seatbelt retrofit system set up in simulation

Analysis Result

The dynamic analysis study evaluated the performance of the patent-pending product [14]. The rollover crash simulation terminated at 1.25 rolls as opposed to 1.5 rolls of the actual accident due to limitation of MADYMO to continue in case of FE belt slip exceeding and causing interaction of FE portion of belt with buckle body. This excessive slip of the belt in the latch plate was caused as a result of mounting the webbing onto the floor causing slacking and allowing excessive lateral inbound motion of buckle causing increased belt transfer in the latching plate. This eventually resulted in excessive vertical excursion of the window side ATD's thus increasing the head reach envelope.

Outcomes

The design [14] was found to have the capability of preventing occupant ejection from the seat. The major cause leading to far side passenger excursion was identified as the webbing length used to attach the seatbelt buckle. These results suggest use of structural member instead of long belt webbing to locate the buckle anchor point close to the side of the seat. Thus, further improvements were made to the design to implement that specific remedy as shown in Figure 2. This improved buckle location also improves the ease for passengers to buckle up. Additionally, the design improvements consider aesthetics, ergonomics and passenger comfort which are covered in the next section.

Ergonomics

Feedback was obtained from representatives of major motor coach manufacturers and operators about different features of design and their significance to passenger comfort and ease of use. Based on that feedback, the anchor support was ergonomically designed considering aesthetics as well as needs for minimal obtrusiveness. The design modification has a location of the buckle anchor point on the anchor beam which was determined by study of variation in different heights of seats. Seat bottom heights vary from 0.25 to 0.38 m from the floor and the lowest height was taken into consideration for location of the anchor point in order to maintain generic product design for different seats. Additionally, the variations in seat attachments such as seat pneumatics and foot rests were considered. To achieve clearances, a curvilinear beam design for anchor support with enough leg room for passenger comfort was developed as shown in Figure 2.

Another salient feature of the product design is the ease of installation which includes accessible bolting locations as well as a side mount allowing for adjustment when mounting on the side railing. Furthermore, to ensure passenger aesthetics the post structure was designed to be sleek. Additionally, to address the safety concern for any rear unbelted passenger during a crash, a solution has been developed for effective and efficient damping of impacts to prevent any undue injuries from a metal structure. The added padding would also serve as a cover around the retractor and belt on the post. Additional care was taken to minimize obstruction to access of a window seat and emergency egress from the same. This consideration lead to optimization of the cross-section of the post for adequate knee clearance.

A slider mechanism for shoulder strap adjustment is accommodated by this design to account for variations in the height of passengers. The slider device could be an existing product [23] and provide recommended safety for passengers of all heights. The following section describes further improvements under development.

Optimization

The anchor support beam geometry was found to have varying stresses along its length thus it can be optimized using topology optimization. Such optimization in geometry would lead to reduction in weight as well as costs. For example, a square cross-section for the anchor support was used which can be further optimized by study of the resultant direction of forces. Opportunities also exist to modify the shape of the post and other areas to have more hollowed sections where the stresses are lower. An achievable goal of reduction of the weight of the entire casted structure to about 9 kg is now being pursued to exceed the targeted cost and weight benchmarks. In parallel, frontal impact scenario simulations are required to evaluate pelvis biomechanics to prevent submarining.

Summary/Conclusions

The product described in this final report meets the FMVSS 210 standards and improve crashworthiness and occupant protection performance in a more affordable than other alternatives. Dynamic simulation of rollover scenarios shows that the product will restrain passengers in their seats. The product is designed for aesthetics, passenger comfort and ease of use. Estimates show that the installed cost will be about a third of the alternative of replacing all seats in the bus, which is no longer necessary with this design. The mitigation of such previous cost barriers combined with compatibility with most any seating configuration could aide adoption and implementation. Furthermore, a known solution that is feasible to implement and easy to use could help to encourage increased seatbelt use in motor coaches over time.

Recommendations

Implementation of this solution will best be accomplished within and by the bus industry. To that end, the most likely adopters of this technology were identified, the technology was presented to the leading candidates and CAD models under NDA were provide to American Seating, the most willing candidate. From there, adoption will come down to an economic value proposition for American Seating. The most likely driver will be a greater public outcry from passengers for the safety provided by seatbelt availability on buses. Our observations indicate this is an awareness issue in that passengers feel safer on buses without seatbelts than they actually are. Thus, future research efforts may be best directed toward understanding causes and influences of passenger behavior and attitudes about safety and the resulting costs and benefits of such safety solutions.

To further promote this work, a comprehensive web link is available [24]. Furthermore, the accomplishments of this project were presented to NHTSA. NHTSA, in response, began promoting these safety benefits [25].

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