TP 14243E

INTERCITY BUS WEIGHT REDUCTION PROGRAM
Phase II

A Design Investigation for Lightweight Intercity
Bus Roof and Floor Components

Prepared for

Transportation Development Centre
of
Transport Canada

by

Prévost Car Inc.
Martec Limited
ADS Groupe Composites

April 2003

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16. Abstract

This study is the second phase of a three-phase project to develop lightweight intercity buses. From the findings of the conceptual design in the first phase, two bus structural components, the floor and roof, were selected for detailed design. The development of these designs from concept to prototype is the basis of the work performed for this project.

Current lightweight manufacturing techniques were studied to determine their potential application for manufacture of intercity buses. Two techniques emerged for continued study: an all aluminium-fastened design, and a hybrid design in which different materials such as metals, foams and composite materials are combined to form structural components.

Detailed designs were developed for the roof and floor based on practical requirements for each component utilizing the two manufacturing techniques. A detailed cost and weight study was performed for many advanced engineering materials to identify potential savings. As a result of the evaluation, no materials yielded significant savings over the others; therefore, final material selection will be based on material performance rather than cost and weight savings alone.

The designs were carried out using analytical calculations, finite element analysis methods, and physical component testing to select optimal materials and configurations. Two hybrid floor designs and one hybrid roof design emerged as the leading designs for prototype development.

Full-scale prototypes were fabricated for the hybrid and all aluminium-fastened designs to discern the viability of each design for full-scale production. Continued work is progressing to select the optimum roof and floor component design for production and road testing.

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16. Résumé

La présente étude est la deuxième des trois phases d'un projet de conception d'autocars allégés. À partir des conclusions de la phase 1, c.-à-d. la phase de définition conceptuelle, deux éléments de structure ont été retenus pour la phase de conception détaillée, soit le toit et le plancher. Les travaux de la présente phase visaient essentiellement la transposition des concepts en prototypes.

Les chercheurs se sont penchés sur la possibilité d'appliquer les techniques actuelles de fabrication d'éléments allégés à la construction d'autocars. Deux techniques présentaient un intérêt particulier : un concept tout aluminium avec assemblage, et un concept hybride qui combine différents matériaux, comme des métaux, des mousses et des composites, pour produire des éléments de structure.

Des concepts détaillés de toit et de plancher faisant appel aux deux techniques de fabrication ont été élaborés, en fonction de critères pratiques définis pour chacun des éléments. Pour déterminer les économies potentielles que pourraient générer divers matériaux avancés, une étude approfondie de leur coût et de leur poids, tels que mis en œuvre dans les éléments envisagés, a été réalisée. Cette évaluation a permis de conclure qu'aucun des matériaux ne se détachait des autres en ce qui a trait aux économies générées; le choix définitif des matériaux ne devra donc pas seulement reposer sur leur coût et leur poids, mais aussi sur leurs performances.

Les concepts ont été élaborés après que des calculs analytiques, des méthodes d'analyse par éléments finis et des essais physiques eurent permis de choisir les matériaux et les agencements optimaux. Deux concepts hybrides de plancher et un concept hybride de toit sont ressortis comme les concepts les plus intéressants pour le prototypage.

Des prototypes en vraie grandeur des concepts hybrides et du concept tout aluminium avec assemblage ont été construits afin de vérifier dans quelle mesure ces concepts se prêtent à la production en grandeur réelle. Les travaux se poursuivent en vue de choisir les concepts de toit et de plancher optimaux pour la production et les essais sur route.

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EXECUTIVE SUMMARY

This report presents the results of the second phase of a study into the development of lightweight designs for intercity buses. A project team of Prévost Car, Martec Limited, and ADS Group Composites performed the work with funding aid provided by the Transportation Development Centre of Transport Canada and the Canadian Lightweight Materials Research Initiative (CLiMRI).

Historically, the weight of intercity buses has steadily increased over, the past couple of decades. This is true of Prévost Car buses with the exception of the past few years, where increases in the weight of Prévost buses have been curbed. This "levelling-off" in weight is the result of an extensive multi-year weight reduction program to offset the weight gains from additional equipment required by ever increasing customer demands and to comply with newly introduced governmental weight regulations. In addition, Prévost Car, as a corporate entity, recognizes the importance of helping Canada reach its goals regarding ratifying the Kyoto Accord.

Part of the global Prévost weight reduction initiative is a three-phase advanced engineering project to develop lightweight intercity bus structural components. The first phase of this project, which was completed in January 2000 (see TP 13560E), resulted in the development of several lightweight design concepts for the roof, floor, and side truss components of the bus. The advanced engineering project has currently completed its second phase, which began in February 2001. This phase involved the selection of the most promising concepts of Phase I for detailed design and prototyping. The third and final phase will be the production of a prototype vehicle utilizing the lightweight designs.

The objectives of the second phase of the advanced engineering project were to determine the most efficient methods of producing lightweight intercity bus structural components (in terms of weight and costs) and, based on these methods, to design and produce prototypes of these components. Phase II aimed to reduce the weight of the floor and roof structural components by 50 percent without significant cost increases. Based on the current weight of the roof and floor, this translated into a weight saving of 720 kg (1584 lb.). This project was one of many internal projects under way at Prévost Car, whose overall objective is to further reduce bus weight by an additional 150 kg (330 lb.) per year.

A literature review was performed to identify current lightweight bus structures on the market. Two state- of-the-art manufacturing techniques were common to the designs. The first, a hybrid approach where composite sandwich panels are joined together with aluminium extrusions, was used for the D-Bus and Bova Majiq. The second, a one-piece composite monocoque structure, was used for the Advanced Technology Transit Bus (ATTB) and NABI's Compobus. Although the lightweight designs were not completely applicable to Prévost's planned production methods for the lightweight structure, information on fabrication, techniques, and state-of-the-art material usage was collected.

During the project, many series of meetings took place with Prévost product experts and external team members to identify the important considerations for any new lightweight bus design. From the collected information, a checklist was developed for the floor and roof components. This checklist identified the requirements for the components that any new design must meet. The goal of the designs was to match the stiffness of the current structure while reducing weight. A prime requirement for any of the new designs was that they be

readily integrated into the Prévost production line without any significant infrastructure changes. This necessitated an evolutionary approach rather than a high-risk revolutionary one.

From the Phase I results and the review of current lightweight bus designs, three design concepts were identified and examined. The first concept was a hybrid design where metals, foams, and composite materials are combined in the design of structural components. Adhesives serve as the structural attachment mechanism for the components. The second was an all-aluminium design strategy, whereby structural attachment is achieved either through welding or by means of a mechanical fixation system, such as Säffle's System 2000 and ALCAN's Alusuisse system. The third concept was a variation of the hybrid design in which the major components are made solely from composites. Special composite manufacturing processes allow for the large monocoque parts to be fabricated.

Upon further analysis, the all aluminium-welded concept was rejected as a viable manufacturing option. Although welding aluminium is not an uncommon practice, implementing it on such a large scale would be costly. Aluminium oxide forms readily on the surface and must be removed before welding. In addition, steel dust can contaminate the surface of aluminium, requiring further surface preparation before welding. Welding can cause significant distortion of aluminium and a loss of mechanical properties requiring heat treatment. Heat treatment of large components is prohibitively expensive. To compensate for the loss of strength, large safety factors must be employed to welded aluminium joints, potentially increasing member size and therefore weight. Therefore, the welded aluminium strategy was eliminated from as a potential process.

Although welding of aluminium was not feasible for this application, Prévost still saw great potential for weight savings with aluminium. Accordingly, the mechanically fastened aluminium space frame was still strongly considered. The basis for an all aluminium-fastened concept is a framework of aluminium extrusions that are connected at the joints through mechanically fastened gusset plates. Two examples of this fabrication technique are Säffle's System 2000 and ALCAN's Alusuisse system. This technique is shown in Figure 1. The potential advantages and disadvantages of this type of structure as viewed by Prévost are as follows:

Advantages:

- Flexibility for the motor home options;
- Minimum tooling;
- Precise structure with no welding distortion;
- ALCAN/Alusuisse experience available for consultation.

Disadvantages:

- Potential for galvanic corrosion in crevices;
- Assembly is labour intensive;
- High thermal conductivity of aluminium can create problems with condensation.

To determine the viability of the all aluminium-fastened concept, ALCAN initiated a study to determine the strength and stiffness of a Prévost Car intercity bus structure fabricated using this technique. The study vehicle selected was the Prévost H3-45 coach with an all stainless steel structure. The results of the ALCAN study indicate that an aluminium structure can be designed to match the stiffness of the current steel structure with an overall weight savings of 559 kg but a 13 percent cost increase for the affected components.

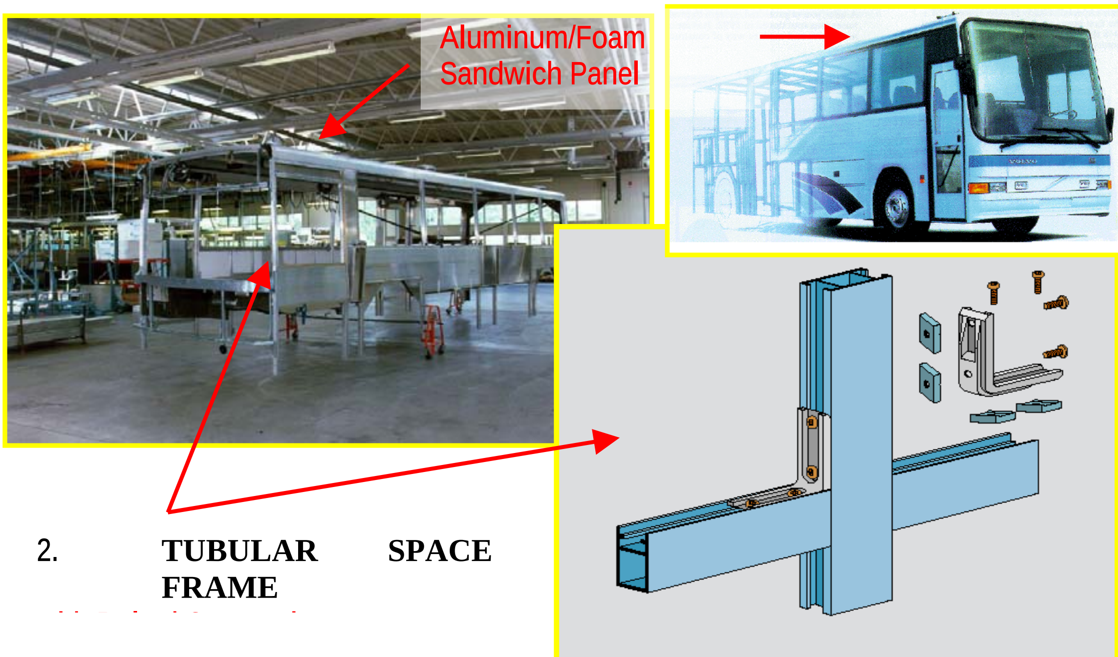

FIGURE 1: Example of the All Aluminium-Fastened Design Concept
(Photos courtesy of Säffle Karosseri AB and ALCAN Inc.)

From the information gathered in Phase I, the hybrid concept showed the most promise for lightweight components. The hybrid design selected for the lightweight bus structure was composed of a series of different structural components including sandwich panels, aluminium extrusions, composites, and steel as shown in the sketch of a typical bus cross section of Figure 2.

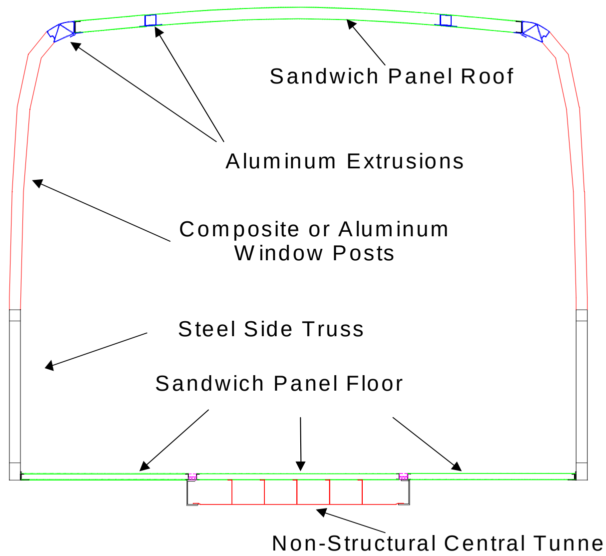

FIGURE 2: Lightweight Bus Structure Utilizing the Hybrid Approach

An initial design was proposed for both the floor and roof using this manufacturing method. For the roof, the sandwich panel is constructed in one piece and utilizes two outboard extrusions as the longitudinal edges to join to the top of the window posts. Two inboard extrusions are imbedded into the sandwich panel to serve as the inboard attachment point for the parcel racks. The sandwich panel utilizes metal or FRP skins over a structural core. This roof design is demonstrated in Figure 3.

The advantages and disadvantages of the hybrid roof design as viewed by Prévost are as follows:

Advantages:

- Flexibility for the motor home options;
- Pre-assembly of the complete roof, including parcel racks and interior finishing;
- Simplification of the window posts using optimized composite materials.

Disadvantages:

- Equipment required for handling of large parts;
- Difficulty of matching the stiffness of steel window posts;
- Complexity of bonding large components together.

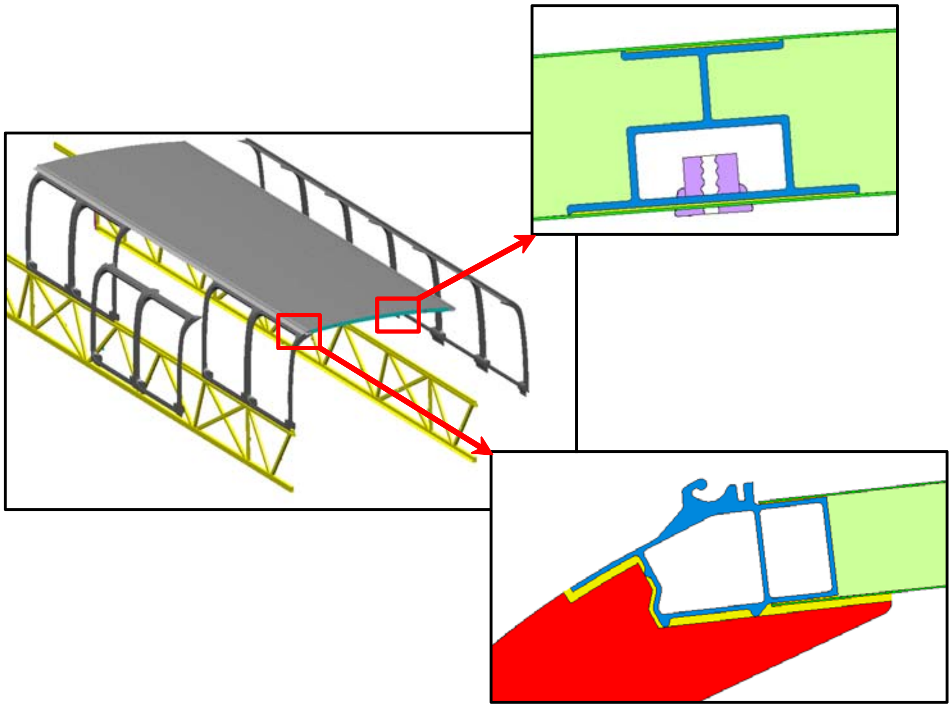

FIGURE 3: Proposed Lightweight Hybrid Roof Design

The floor design uses a similar sandwich panel. Three sandwich panels make up the floor, one under each seating row and a third central aisle section. Again, the sandwich panel has metal or FRP skins over a structural core. Perimeter extrusions would be used to close in the panel edges should they be required. The proposed floor design is presented in Figure 4.

The advantages of the hybrid floor design were determined to be as follows:

- Increased torsional stiffness of the vehicle;
- Easier access to service tunnel during manufacturing;
- Better thermal insulation as compared to wood;
- Less interior finishing needed to install the flooring.

The disadvantages of this type of design were the following:

- Handling of large components;
- Reduction of flexibility for motor home (requires new method to make access hole).

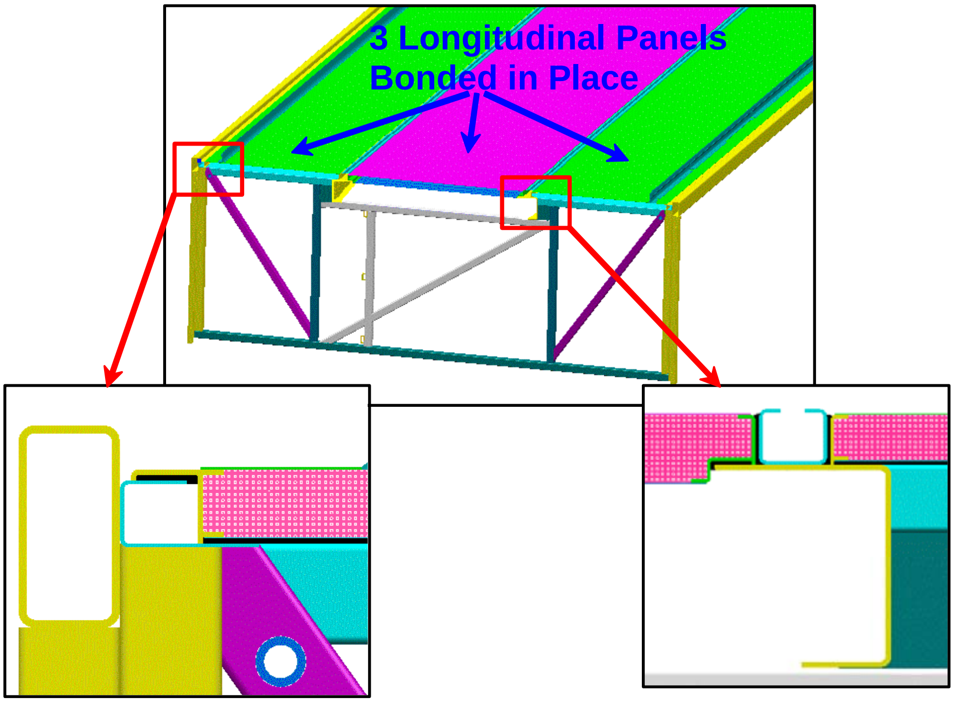

FIGURE 4: Proposed Lightweight Hybrid Floor Design

The third concept, the modified hybrid design, applied only to the roof. In this design, the complete roof panel and window posts are fabricated in one integral unit. These units could vary in length from a single section to, ideally, the full length of the vehicle. A roof design utilizing this concept is shown in Figure 5.

The advantages of the all-composite hybrid roof design were determined to be as follows:

- Potential for good rollover performance;
- Pre-fitting of interior finishing before attaching to vehicle.

The disadvantages of this type of design were the following:

- Lack of flexibility for the motor home;
- Joints in the roof have the potential for water leaks.

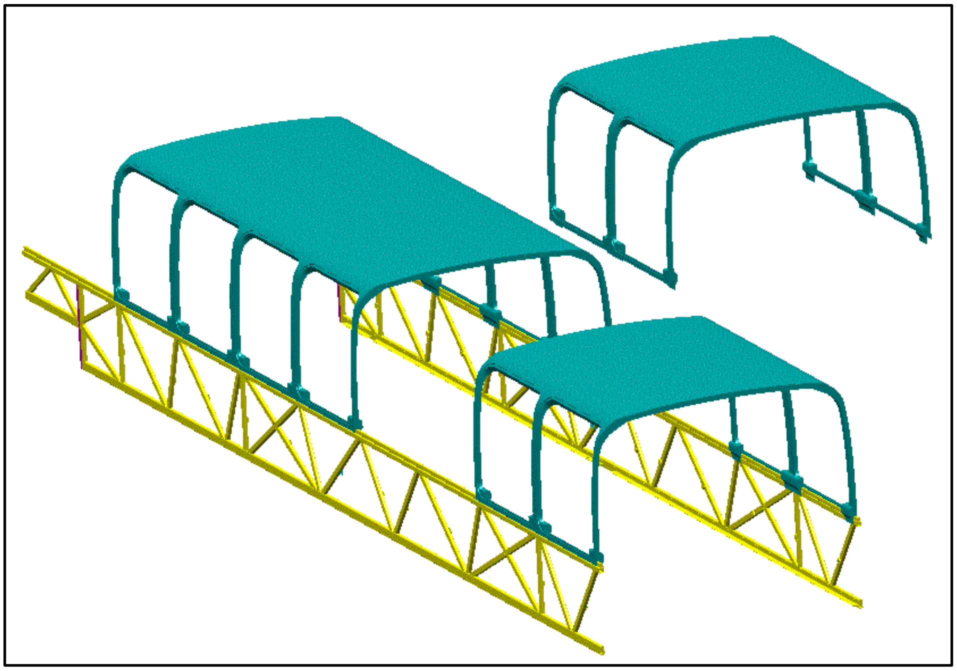

FIGURE 5: All Composite Modified Hybrid Roof Design

The fundamental criteria of the new designs were that they be lightweight and match the stiffness of the current bus structure while keeping within the design stresses. To meet these criteria, a structural analysis was performed to determine the dimensions of the roof and floor components. Three load cases were used: a 3 *g* vertical load, a torsional load, and a rollover load.

The roof structural analysis was performed by first isolating a section of the current roof structure. The structure consisted of a section of the roof, one window post, and a section of the side truss and floor. This section was used as a baseline for comparison with the new designs. The results showed that the proposed design matches the stiffness of the original roof structure very closely.

The floor analysis was performed on a complete bus model that incorporated the new floor designs. Again, the results showed very good agreement with the current structure results.

A weight and cost analysis comparing the current floor and roof designs to the new lightweight designs is shown in Tables 1 and 2, respectively. The weight and cost of materials and fabrication for the new designs were provided by suppliers and fabricators, and the cost of manufacturing was estimated by the Prévost process department.

TABLE 1: Cost and Weight Analysis of Proposed Floor Designs

Concepts	Weight		Weight Saved		Weight Saved (%)	Cost Saved (%)
	kg	lb.	kg	lb.		
Original Floor	762	1676				
I: 3 Full Length Floor Panels with FRP skins and Klegecell foam core	379	834	383	843	50%	-17%
II: 3 Full Length Floor Panels with FRP skins and Balsa core	378	832	384	845	50%	-14%
III: 3 Full Length Floor Panels with FRP skins and Nidacore core	369	812	393	864	52%	-12%
IV: 3 Full Length Floor Panels with FRP skins and Corecell core	387	851	375	825	49%	-25%
V: 3 Full Length Floor Panels with Aluminum skins and Klegecell foam core	430	945	333	732	44%	-20%
VI: 3 Full Length Floor Panels with Aluminum skins and Balsa core	429	943	333	733	44%	-16%
VII: 3 Full Length Floor Panels with Aluminum skins and Nidacore core	420	923	342	753	45%	-15%
VIII: 3 Full Length Panels Aluminum skins and Corecell core	437	962	325	714	43%	-28%
IX: 3 Full Length Floor Panels with Al/SS skins and Klegecell foam core	486	1069	276	607	36%	-27%
X: 3 Full Length Floor Panels with Al/SS skins and Balsa core	485	1067	277	609	36%	-24%
XI: 3 Full Length Floor Panels with Al/SS skins and Nidacore core	476	1048	286	629	38%	-22%
XII: 3 Full Length Floor Panels with Al/SS skins and Corecell core	494	1087	268	590	35%	-35%

Capital cost investments for the floor and roof designs are not provided Tables 1 and 2. It was decided that capital costs would be considered as overhead, and as long as the payback period for any design was within a given period, the design was acceptable. In addition, Prévost did not want to eliminate certain designs that could provide significant weight reduction because of this initial capital cost.

TABLE 2: Cost and Weight Analysis of Proposed Roof Designs

Concepts	Weight		Weight Saved		Weight Saved (%)	Cost of Concept ($CAN)	Cost Saved ($CAN)	Cost Saved (%)
	kg	lb.	kg	lb.				
Original Roof	599	1317				6883		
I: Monocoque Infused One Piece Roof With Integrated Window Posts with FRP skins and Klegecell foam core	273	600	326	718	54%	8276	-1393	-20%
II: Monocoque Infused One Piece Roof With Integrated Window Posts with FRP skins and Balsa core	283	622	316	695	53%	8258	-1375	-20%
III: Monocoque Infused One Piece Roof With Integrated Window Posts with FRP skins and Nidacore core	297	654	302	664	50%	8094	-1211	-18%
IV: Monocoque Infused Four Piece Roof With Integrated Window Posts with FRP skins and Klegecell foam core	279	614	320	703	53%	9099	-2216	-32%
V: Monocoque Infused Four Piece Roof With Integrated Window Posts with FRP skins and Balsa core	289	636	310	681	52%	9081	-2198	-32%
VI: One Piece Roof Top, Bonded Window Post Modules to Aluminum Extrusions, using FRP skins and Klegecell foam core	318	699	281	618	47%	9139	-2256	-33%
VII: One Piece Roof Top, Bonded Window Post Modules to Aluminum Extrusions, using FRP skins and Balsa core	342	753	257	565	43%	9764	-2881	-42%
VIII: One Piece Roof Top, Bonded Window Post Modules to Aluminum Extrusions, using Al skins and Klegecell foam core	341	751	258	567	43%	9376	-2493	-36%
IX: One Piece Roof Top, Bonded Window Post Modules to Aluminum Extrusions, using AL skins and Balsa core	366	804	233	513	39%	9251	-2367	-34%

The results of the cost analysis showed that although all of the design configurations would represent an increase over current costs, some of these expenses were not significant, particularly for the proposed floor designs. The lowest of the cost increases was 12 percent for the floor designs and 18 percent for the roof designs. Consequently, the floor concepts would have a lower cost impact than the roof concepts. These values were considered to be the targets for the increased costs, and it was also expected that these costs would decrease as the designs were finalized.

At this point in the analysis there was no design or material configuration that offered a significant cost or weight savings over the other designs. Consequently, the detailed design of the roof and floor continued even though selection of the material configurations had not been finalized. Final selection would be based on material performance as compared to the set of design criteria developed by Prévost's in-house product experts.

As the project progressed into the detailed design stage of the roof and floor components, it became evident that the roof design would be much more complex than the floor design, and would be difficult to complete within the scope of the project. While the design continued with the ultimate goal of manufacturing a prototype of the new lightweight roof, this would have to be completed as an internal Prévost project following the conclusion of the Phase II project. Because the floor offered a much simpler design that could be much more readily integrated into the Prévost coach, a final design including prototyped panels would be delivered within the scope of Phase II.

The detailed design of the floor was composed of two parts: the global design as established from the previously performed structural analysis; and the local design. The local design requirements were: resistance to marking or denting as result of a dropped object; resistance to concentrated load; a local stiffness requirement for passenger walking loads; and noise attenuation properties. A series of tests was developed to determine the performance of the new designs subjected to the local loads. As a result of these tests, the skin material was identified for the floor panels and the core material was narrowed down to two leading materials. Prototype panels that utilized each core material were manufactured for further full-scale testing.

Similarly, the detailed roof design comprised both global and local design considerations. The global structural requirements were addressed from the earlier analysis. The other global consideration was the thermal properties of the roof panel. Therefore, a thermal analysis of the leading designs was performed. From the analysis, the constituent dimensions were changed to match the thermal properties of the current roof without the need for additional insulation.

The local design of the roof focussed on the structural attachment of the roof components and the stiffness of the window posts. Adhesives were used as the attachment mechanism for the roof to the bus structure. Two sets of experimental tests were developed to test this structural connection and window post stiffness. Upon completion of the testing, Prévost selected an adhesive that met the needs of this joint. The only window posts selected for testing were those manufactured from composites. It was determined that aluminium posts were not suited for this region of the bus structure because of galvanic corrosion issues between the post and the stainless steel side truss.

Testing of the initial prototype posts showed that the composite post did not match the stiffness of the current welded steel posts. This was attributed to design complications coupled with manufacturing problems that led to the premature failure of the window posts. With each iteration of the post design, performance of the part improved. However, in order to confirm that a composite post that matches the stiffness of the current steel posts could in fact be produced, a post made entirely of carbon fibre was produced and tested. The experiment proved to be a success, although the fibreglass post is not as stiff as the current steel post, the carbon fibre post is stiffer. It is still expected that the final composite post will be composed of both fibreglass and carbon fibre as initially proposed. The window post testing/validation will continue within the scope of Prévost's internal weight reduction program following the end of the Phase II advanced engineering project.

Other areas of the bus design (apart from the major components) were examined as part of the detailed design process. Proper adhesive selection was crucial to the success of any of the new designs. Consequently, Prévost staff spent considerable time learning how to work effectively with adhesives, gaining experience, and testing their physical properties. In addition, the feasibility of incorporating seatbelts into the vehicle was briefly studied with respect to the design of a new seat track. Local connection details were also incorporated into the new designs so that they would easily mate with the existing Prévost structure. As well as addressing the engineering issues regarding the designs, manufacturability of the designs was also considered. For future reference in other lightweight design studies, a Design Manual was developed detailing the complete design process.

Based on the results of the detailed design process, the lightweight design was finalized for the floor component. Two leading core materials met the needs of the floor and one material met the skin requirements. Prototype panels were ordered, fabricated from each core material, and installed in a vehicle mock-up section as seen in Figure 6. The prototype panels allowed for final verification of the floor panels and gave Prévost staff an opportunity to examine potential installation techniques that might be used on the production line. Each floor design proved to meet the requirements of the floor.

Final selection will be based on the production cost and on an acoustical analysis that has yet to be performed. It was decided that rather than perform the acoustical analysis in a laboratory environment, it would be performed on the road-worthy prototype vehicle. The overall acoustical properties of the floor are quite small when compared to the complete acoustical treatment of a completed vehicle. It is expected that a much more accurate representation of noise would be obtained from a full vehicle test. Full size prototype panels could be fitted to a vehicle for road testing later in 2003.

As a result of the detailed design of the roof, no single concept emerged as the preferred design choice. The one-piece composite roof module was the most cost effective and offered the greatest weight savings, but its implementation required the most in terms of capital costs. In addition, the results of the window post testing showed that there were still some difficulties in infusing a part as complicated as a window post. Prototype parts were ordered for both designs to be outfitted to the vehicle mock-up section in which the floor designs had been installed. The prototype parts for the one-piece composite roof module and sandwich panel roof designs are shown in Figures 7 and 8, respectively.

The prototype roof parts were not production quality and therefore served as demonstration pieces of the roof designs. They did prove valuable for Prévost and the fabricators to gain a better understanding of fabrication techniques, handling and fixation of the parts. The installation of the roof components onto the steel structure was very similar for each design except that the window modules had to be attached to the roof panel first before they were attached to the structure. Valuable experience was gained from the production of these parts, and new challenges were identified for implementing the new designs into the Prévost line.

FIGURE 6: Mock-up Installation of Prototype Floor Panels

FIGURE 7: Mock-Up Installation of the One-Piece Composite Roof Module

FIGURE 8: Mock-Up Installation of the Sandwich Panel Roof Design

To aid in the assessment of the all-aluminium design, Prévost ordered a mock up of a system 2000 bus body from Prévost's sister company, Säffle, in Sweden, for evaluation before ALCAN became involved with the project. The mock up gave Prévost valuable insight into the manufacturing and assembly of such a fabrication technique. The Säffle mock up is shown in Figure 9.

FIGURE 9: Säffle System 2000 Bus Cross-Section Mock Up

The knowledge gained from the Phase II project will be used in the development of future Prévost vehicles. The lightweight floor and roof designs from this project will be used as building blocks for modules that serve as the framework of the vehicle. The significance of the change of scope from previous phases of work is that some of the new modular designs may be specific to a certain vehicle type (e.g., a different roof module could be used on a motorhome versus a coach).

In addition, the designs will be developed with a goal to reduce the assembly time on the line and reduce the number of parts that need to be manufactured. This will also filter down to the purchasing department, where the number of parts that must be purchased will be substantially reduced.

In order to utilize new technologies in low-volume manufacturing applications, Prévost would like to see research performed by industry on state-of-the-art manufacturing techniques and materials. Research areas specifically identified by Prévost are cost-effective fabrication techniques for low-volume applications as well as cost-effective fabrication techniques for large composite parts. Prévost sees great potential for weight savings utilizing new materials and part manufacturing techniques. Considerable work has been done in Europe on these topics but has been slow to occur in North America.

The outcome of this phase of the advanced engineering project, along with the other internal weight reduction programs, will greatly enhance Prévost Car’s position as a major North American intercity bus manufacturer. Although more work is needed in developing the final roof design, it will be continued within Prévost as an internal initiative. In addition, future initiatives show great promise in producing lightweight vehicles utilizing the designs of the Phase II project in combination with the newest ideas on the modular approach.

SOMMAIRE

Le présent rapport rend compte de la deuxième phase d'une étude qui vise l'élaboration de concepts «allégés» pour la construction d'autocars. Cette phase a été réalisée par une équipe formée de représentants de Prévost Car Inc., de Martec Limited et de ADS Groupe Composites, avec l'appui financier du Centre de développement des transports de Transports Canada et de l'Initiative canadienne de recherche sur les matériaux légers (ICRMLe).

Un coup d'œil sur le passé nous apprend que le poids des autocars a constamment augmenté au cours des deux dernières décennies. Les véhicules construits par Prévost Car n'échappent pas à cette règle, sauf que ces dernières années, les gains de poids ont été moins brutaux. Ce «plafonnement» du poids des autocars Prévost est le résultat d'un vaste programme pluriannuel d'allégement des autocars, par lequel la société entend contrebalancer les gains de poids qui accompagnent l'ajout d'équipements destinés à satisfaire une clientèle de plus en plus exigeante, et à se conformer aux nouvelles réglementations sur le poids des véhicules. Et en tant que personne morale, Prévost Car trouve important de participer à l'atteinte des objectifs que le Canada s'est fixés en ratifiant le Protocole de Kyoto.

L'initiative d'allégement entreprise par Prévost comprend un projet de conception avancée d'éléments de structure allégés pour autocars. La première des trois phases du projet, qui s'est terminée en janvier 2000 (voir le TP 13560E), a débouché sur plusieurs concepts techniques allégés pour le toit, le plancher et la structure treillis latérale de l'autocar. La deuxième phase a débuté en février 2001 et s'achève par le présent rapport. Elle a consisté à choisir, parmi les concepts élaborés pendant la phase 1, les meilleurs candidats pour une conception détaillée et un prototypage. La troisième et dernière phase consistera à construire un véhicule prototype qui matérialisera les concepts allégés.

Les objectifs de la deuxième phase étaient de déterminer les techniques optimales (tant sur le plan de l'allégement que des coûts) pour fabriquer les éléments de structure d'autocars allégés et, compte tenu de ces techniques, de concevoir et construire des prototypes de ces éléments. En clair, les chercheurs visaient à réduire de 50 p. 100 le poids du plancher et du toit, sans augmentation sensible des coûts de fabrication. D'après le poids actuel du plancher et du toit, cela signifiait un allégement de 720 kg (1 584 lb.). Ce projet n'était que l'un des nombreux projets internes en cours chez Prévost Car, qui s'est fixé comme objectif global de réduire encore le poids de ses autocars de 150 kg (330 lb.) par année.

Une recherche documentaire a d'abord été effectuée pour repérer les structures d'autocars allégés actuellement sur le marché. Deux techniques de fabrication de pointe sont ressorties de cette recherche. La première, utilisée pour le D-Bus et le Bova Majiq, est une technique hybride qui consiste à assembler des panneaux sandwich en matériau composite à l'aide de profilés en aluminium. La deuxième est une structure monocoque en composite en une seule pièce, utilisée pour l'ATTB (*Advanced Technology Transit Bus*) et le Compobus de NABI. Même si ces concepts allégés ne pouvaient pas s'appliquer intégralement aux techniques de production envisagées par Prévost, la recherche a permis de colliger des renseignements sur les techniques d'assemblage et la mise en oeuvre de matériaux avancés.

Tout au cours du projet, les membres de l'équipe de projet ont multiplié les rencontres avec les experts de Prévost et d'autres spécialistes, afin de cerner les facteurs importants à prendre en compte dans la conception d'un autocar allégé, quel qu'il soit. À partir de l'information ainsi recueillie, une liste de contrôle a été établie pour le plancher et le toit. Cette liste de contrôle

énumérait les critères auxquels devait satisfaire tout nouveau concept. En gros, les nouveaux concepts devaient déboucher sur des éléments de structure aussi rigides que les éléments classiques, mais plus légers. Une autre exigence fondamentale était posée : ils devaient s'intégrer facilement à la chaîne de montage de Prévost, c.-à-d. ne nécessiter que des modifications minimes aux équipements d'infrastructure. C'est ainsi qu'une approche évolutive a été préférée à une démarche révolutionnaire à haut risque.

À la lumière des résultats de la phase 1 et de l'inventaire des structures d'autocars allégés sur le marché, trois concepts techniques ont été retenus en vue d'un examen approfondi. Le premier concept, de type hybride, conjugue métaux, mousses et matériaux composites et utilise des adhésifs comme moyen d'assemblage. Le deuxième concept est une stratégie tout aluminium dans laquelle l'assemblage est réalisé par soudage ou par un système mécanique, comme le System 2000 de Säffle et l'Alusuisse d'ALCAN. Le troisième concept est une variante du concept hybride, dans laquelle les principaux éléments sont constitués uniquement de matériaux composites. Des procédés de fabrication spéciaux permettent de réaliser de grosses pièces monocoques en matériaux composites.

Au terme d'une analyse approfondie, le concept tout aluminium avec assemblage par soudage a été écarté, à cause des problèmes liés au soudage de l'aluminium. En effet, même si le soudage de l'aluminium est relativement courant, il serait coûteux d'appliquer ce procédé à grande échelle. Car de l'oxyde d'aluminium apparaît rapidement sur la surface, et il faut l'enlever avant de souder. De plus, la poussière d'acier risque de contaminer la surface d'aluminium, ce qui ajoute une étape à la préparation de la surface avant le soudage. Enfin, le soudage peut entraîner une déformation importante de l'aluminium et une altération de ses propriétés mécaniques, à laquelle il faut remédier par un traitement thermique. Or, les coûts associés au traitement thermique d'éléments de grandes dimensions sont prohibitifs. Pour compenser la perte de résistance, des facteurs de sécurité importants doivent être appliqués aux joints d'aluminium soudés, ce qui peut se traduire par une augmentation de la dimension des éléments et, partant, de leur poids. La stratégie de l'aluminium soudé a donc été écartée.

Même si le soudage de l'aluminium ne pouvait être envisagé pour la présente application, Prévost n'en a pas moins apprécié l'immense potentiel d'allégement offert par l'aluminium. C'est pourquoi le concept d'ossature en aluminium avec assemblage mécanique a été examiné de très près. Ce concept comprend une ossature de profilés d'aluminium assemblés par des goussets fixés mécaniquement. Deux exemples de ce procédé de fabrication sont le System 2000 de Säffle et le système Alusuisse d'ALCAN. Cette technique est illustrée à la figure 1. Voici les avantages et inconvénients potentiels de ce type de structure, selon Prévost :

Avantages :

- souplesse pour les options «autocaravane»;
- outillage minimal;
- dimensions précises sans déformation due au soudage;
- possibilité de profiter de l'expérience d'ALCAN/Alusuisse.

Inconvénients :

- risque de corrosion galvanique dans les interstices;
- assemblage exigeant en main-d'œuvre;

- problèmes de condensation possibles en raison de la forte conductivité thermique de l’aluminium.

Pour déterminer la faisabilité du concept tout aluminium avec assemblage mécanique, ALCAN a entrepris une étude sur la résistance et la rigidité d’une structure d’autocar Prévost assemblée par cette technique. Le véhicule d’essai sélectionné était l’autocar Prévost H3-45 à structure tout acier inoxydable. D’après les résultats obtenus par ALCAN, il serait possible de concevoir une structure tout aluminium qui offrirait la même rigidité que la structure actuelle en acier, mais pèserait 559 kg de moins. Il faudrait alors compter avec une augmentation de 13 p. 100 du coût des éléments touchés.

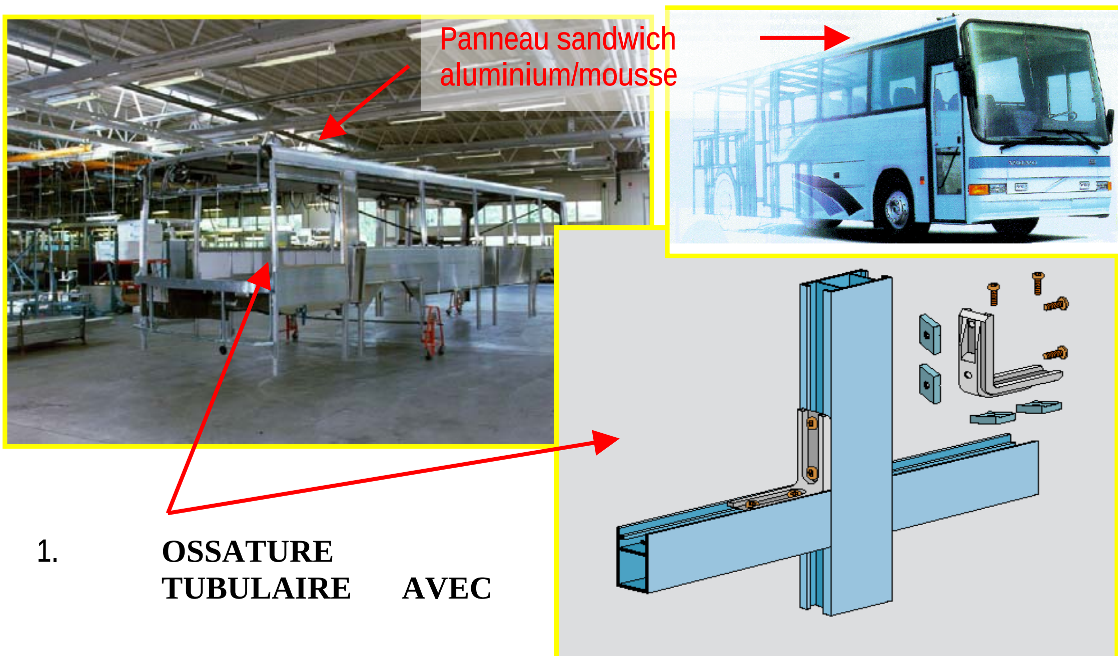

FIGURE 1 : Exemple du concept tout aluminium/assemblage mécanique
(Photos : courtoisie de Säffle Karosseri AB et ALCAN Inc.)

D’après les données recueillies au cours de la phase 1, c’est le concept hybride qui s’avère le plus prometteur pour la fabrication des éléments allégés. Le concept hybride retenu comporte des éléments de structure faits d’un éventail de matériaux, y compris des panneaux sandwich, des profilés d’aluminium, des matériaux composites et de l’acier, comme l’illustre le schéma en coupe d’un autocar classique, à la figure 2.

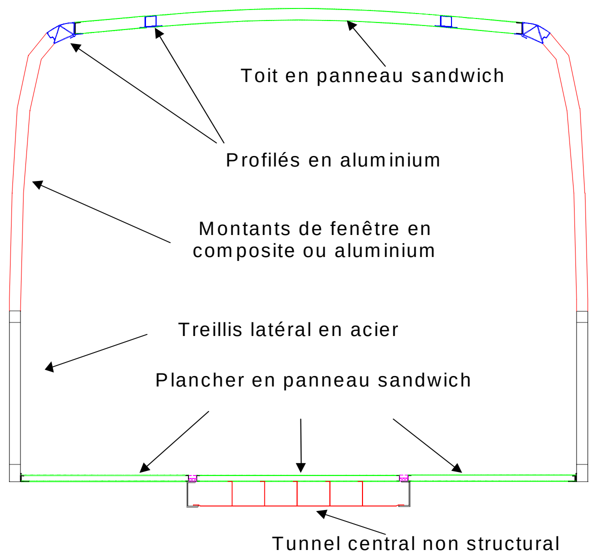

FIGURE 2 : Concept hybride de structure d'autocar allégé

Un premier concept de plancher et de toit utilisant une technique de fabrication hybride a été proposé. Dans le cas du toit, le panneau sandwich est en une seule pièce et il est bordé de part et d'autre par des profilés extérieurs qui sont assemblés au sommet des montants de fenêtre. Deux profilés intérieurs sont noyés dans le panneau sandwich et servent de point d'ancrage aux porte-bagages. Le panneau sandwich est composé d'une âme en matériau structural revêtue de parements en métal ou en plastique renforcé. Ce concept de toit est représenté à la figure 3.

Selon Prévost, le concept hybride de toit comporte les avantages et les inconvénients suivants :

Avantages :

- souplesse pour les options «autocaravane»;
- pré-assemblage de l'ensemble du toit, y compris les porte-bagages et la garniture intérieure;
- simplification des montants de fenêtre, grâce à l'utilisation de matériaux composites optimisés.

Inconvénients :

- équipement nécessaire pour la manutention de pièces de grandes dimensions;
- difficulté d'obtenir des montants de fenêtre en matériaux composites aussi rigides que des montants en acier;
- difficulté de coller des éléments de grandes dimensions.

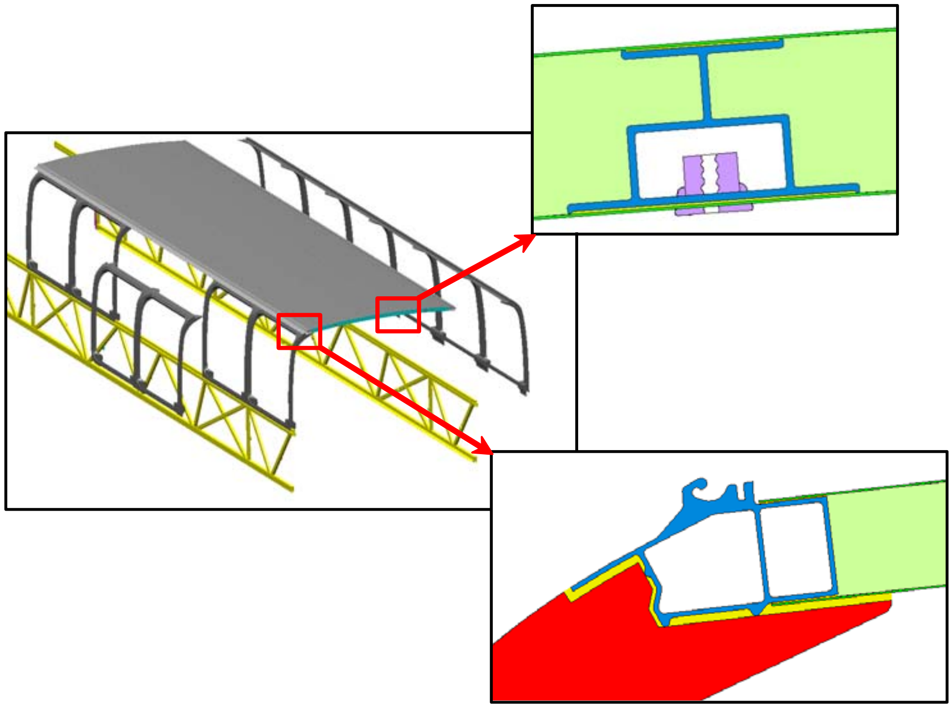

FIGURE 3 : Concept hybride de toit allégé

Le concept du plancher fait appel lui aussi à un panneau sandwich. Trois panneaux sandwich composent le plancher, un sous chaque rangée de sièges et un troisième dans le couloir central. Encore une fois, le panneau sandwich est constitué d'une âme en matériau structural revêtue de parements en métal ou en plastique renforcé. Les profilés périmétriques peuvent servir à ceindre les bords des panneaux, au besoin. Le concept de plancher proposé est présenté à la figure 4.

Voici les avantages associés au concept hybride de plancher :

- meilleure résistance à la torsion du véhicule;
- accès au tunnel d'entretien facilité pendant la fabrication;
- meilleure isolation thermique, comparativement au bois;
- moins de garniture intérieure nécessaire pour le revêtement de plancher.

Voici les inconvénients associés à ce type de concept :

- manutention de composants de grandes dimensions;
- moins de souplesse pour les autocaravanes (besoin d'une nouvelle méthode pour faire un trou d'accès).

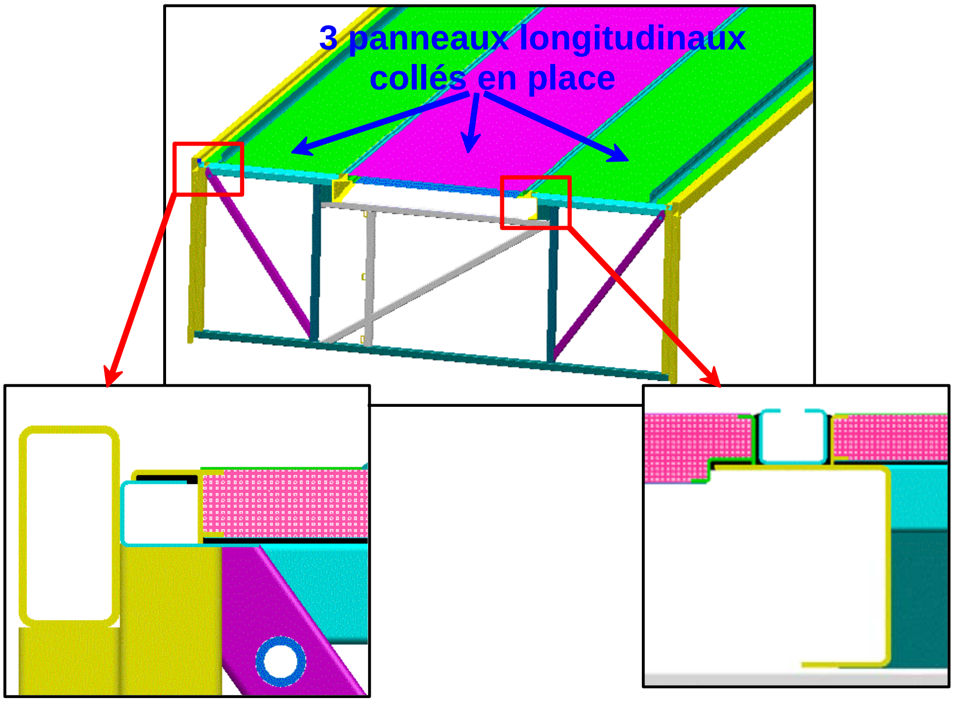

FIGURE 4 : Concept hybride de plancher allégé

Le troisième concept, le concept hybride modifié, n'est appliqué qu'au toit. Il consiste à fabriquer des unités intégrées comprenant le panneau de toit et les montants de fenêtre. Selon leur longueur, ces unités peuvent couvrir une section de l'autocar ou, idéalement, toute la longueur du véhicule. La figure 5 représente un toit fabriqué selon ce concept.

Voici les avantages du concept hybride de toit tout composite :

- bonne résistance en cas de tonneau;
- mise en place des garnitures intérieures avant l'assemblage du toit au véhicule.

Les inconvénients de ce type de toit sont les suivants :

- manque de souplesse pour les autocaravanes;
- risque d'infiltration d'eau par les joints du toit.

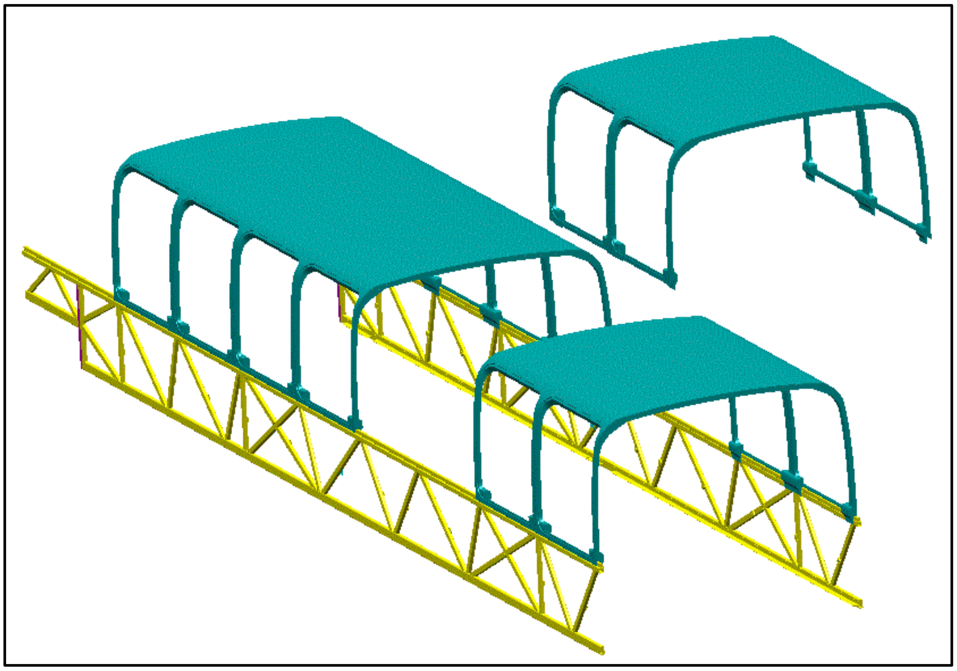

FIGURE 5 : Concept hybride modifié de toit tout composite

Les nouveaux éléments de structure devaient répondre aux critères fondamentaux suivants : être légers, offrir la même rigidité que les éléments de structure des autocars actuels et résister aux contraintes admissibles. Des calculs ont donc été réalisés pour déterminer les dimensions du toit et du plancher compatibles avec ces critères. Trois cas de charge ont été étudiés : une charge verticale de 3 *g*, un effort de torsion et un tonneau.

Pour le calcul du toit, on a d'abord isolé une section de la structure de toit actuelle. Celle-ci comprenait une section du toit, un montant de fenêtre et une section du treillis latéral et du plancher. Cette section a servi de point de repère pour comparer les nouveaux concepts de toit aux toits classiques. Les résultats ont révélé que le concept proposé est quasi aussi rigide que la structure de toit classique.

Le calcul du plancher a été réalisé à l'aide d'une maquette d'autocar complet dans laquelle les nouveaux concepts de plancher avaient été installés. Encore là, une très grande concordance a été constatée entre les résultats des concepts nouveau et classique.

Les tableaux 1 et 2 donnent les résultats respectifs de deux études comparatives du poids et du coût des planchers et des toits actuels avec le poids et le coût des nouveaux concepts de toit et de plancher allégés. Le poids et le coût (matériaux et main-d'œuvre) des nouveaux concepts ont été déterminés avec l'aide des fournisseurs et des ateliers de transformation, tandis que les coûts de fabrication ont été évalués par le service des procédés de Prévost.

TABLEAU 1 : Coût et poids des concepts de plancher proposés

Concepts	Poids		Allégement		Allégement	Économie
	kg	lb.	kg	lb.	(%)	(%)
Plancher existant	762	1 676				
I : 3 panneaux pleine longueur à âme en mousse Klegecell revêtue de plastique renforcé	379	834	383	843	50 %	-17 %
II : 3 panneaux pleine longueur à âme en balsa revêtue de plastique renforcé	378	832	384	845	50 %	-14 %
III : 3 panneaux pleine longueur à âme en Nidacore revêtue de plastique renforcé	369	812	393	864	52 %	-12 %
IV : 3 panneaux pleine longueur à âme en Corecell revêtue de plastique renforcé	387	851	375	825	49 %	-25 %
V : 3 panneaux pleine longueur à âme en mousse Klegecell revêtue de tôles d'aluminium	430	945	333	732	44 %	-20 %
VI : 3 panneaux pleine longueur à âme en balsa revêtue de tôles d'aluminium	429	943	333	733	44 %	-16 $
VII : 3 panneaux pleine longueur à âme en Nidacore revêtue de tôles d'aluminium	420	923	342	753	45 $	-15 %
VIII : 3 panneaux pleine longueur à âme en Corecell revêtue de tôles d'aluminium	437	962	325	714	43 %	-28 %
IX : 3 panneaux pleine longueur à âme en mousse Klegecell revêtue de tôles d'aluminium/acier inoxydable	486	1 069	276	607	36 %	-27 %
X : 3 panneaux pleine longueur à âme en balsa revêtue de tôles d'aluminium/acier inoxydable	485	1 067	277	609	36 %	-24 %
XI : 3 panneaux pleine longueur à âme en Nidacore revêtue de tôles d'aluminium/acier inoxydable	476	1 048	286	629	38 %	-22 %
XII : 3 panneaux pleine longueur à âme en Corecell revêtue de tôles d'aluminium/acier inoxydable	494	1 087	268	590	35 %	-35 %

Les chiffres des tableaux 1 et 2 ne comprennent pas les coûts d'immobilisation que supposent les nouveaux concepts techniques : il a en effet été décidé de considérer les coûts d'immobilisation comme des frais généraux, et de considérer acceptable tout concept dont la période de récupération ne dépassait pas une limite donnée. De plus, Prévost se refusait à devoir éliminer d'emblée certains concepts qui promettaient un allégement important, en raison de ces coûts d'immobilisation.

TABLEAU 2 : Coût et poids des concepts de toit proposés

Concepts	Poids		Allégement		Allégement (%)	Coût du concept ($ CAN)	Économie ($ CAN)	Économie (%)
	kg	lb.	kg	lb.				
Toit existant	599	1 317				6 883		
I : Toit monocoque d'un seul tenant à montants de fenêtre intégrés, moulé par infusion, à âme en mousse Klegecell revêtue de plastique renforcé	273	600	326	718	54 %	8 276	-1 393	-20 %
II : Toit monocoque d'un seul tenant à montants de fenêtre intégrés, moulé par infusion, à âme en balsa revêtue de plastique renforcé	283	622	316	695	53 %	8 258	-1 375	-20 %
III : Toit monocoque d'un seul tenant à montants de fenêtre intégrés, moulé par infusion, à âme en Nidacore revêtue de plastique renforcé	297	654	302	664	50 %	8 094	-1 211	-18 %
IV : Toit monocoque en quatre pièces à montants de fenêtre intégrés, moulé par infusion, à âme en mousse Klegecell revêtue de plastique renforcé	279	614	320	703	53 %	9 099	-2 216	-32 %
V : Toit monocoque en quatre pièces à montants de fenêtre intégrés, moulé par infusion, à âme en balsa revêtue de plastique renforcé	289	636	310	681	52 %	9 081	-2 198	-32 %
VI : Toit d'un seul tenant à modules de montants de fenêtre collés à des profilés d'aluminium, à âme en mousse Klegecell revêtue de plastique renforcé	318	699	281	618	47 %	9 139	-2 256	-33 %
VII : Toit d'un seul tenant à modules de montants de fenêtre collés à des profilés d'aluminium, à âme en balsa revêtue de plastique renforcé	342	753	257	565	43 %	9 764	-2 881	-42 %
VIII : Toit d'un seul tenant à modules de montants de fenêtre collés à des profilés d'aluminium, à âme en mousse Klegecell revêtue de tôles d'aluminium	341	751	258	567	43 %	9 376	-2 493	-36 %
IX : Toit d'un seul tenant à modules de montants de fenêtre collés à des profilés d'aluminium, à âme en balsa revêtue de tôles d'aluminium	366	804	233	513	39 %	9 251	-2 367	-34 %

L'analyse des coûts a révélé que tous les concepts sans exception entraîneraient une augmentation des coûts. Mais certaines des augmentations sont minimes, en particulier dans le cas du plancher. Les augmentations les plus faibles se chiffrent à 12 p. 100 pour le plancher et à 18 p. 100 pour le toit. Ainsi, un nouveau concept de plancher aurait moins de répercussion sur les coûts qu'un nouveau concept de toit. Ces chiffres ont servi de valeurs limites aux augmentations de coûts, et on s'attendait même à ce qu'après peaufinage des concepts, les hausses de coût n'atteignent même pas ces valeurs.

Au terme de l'analyse comparative, aucun des concepts ou agencements de matériaux ne se détachait nettement des autres pour ce qui est de l'allégement et des économies possibles. Les travaux de conception détaillée du plancher et du toit se sont donc poursuivis, même si la sélection définitive des configurations de matériaux n'avait pas été faite. Ce choix serait fait en fonction des performances des matériaux par rapport à un ensemble de critères de calcul mis au point par les experts de Prévost.

Au fur et à mesure qu’avançait la conception détaillée du toit et du plancher, il est devenu clair que la conception du toit était beaucoup plus complexe que la conception du plancher, et qu’il ne serait pas possible de respecter l’échéance du projet. Les chercheurs ont quand même poursuivi leurs travaux de conception en étant bien conscients qu’ils ne pourraient réaliser leur objectif ultime, soit la construction d’un prototype du nouveau toit allégé, qu’après la fin de la phase 2, dans le cadre d’un projet interne de Prévost. Comme le plancher était beaucoup plus simple à concevoir et plus facile à intégrer dans l’autocar Prévost, le concept définitif du plancher, y compris les prototypes de panneaux, allait pouvoir être livré à temps.

La conception détaillée du plancher comportait deux volets : une conception globale, découlant du calcul des structures, et une conception «locale». Cette dernière devait répondre à divers critères : résistance au marquage ou à l’indentation pouvant résulter de la chute d’un objet; résistance à une charge concentrée; critère de rigidité locale à la mesure des charges dues au déplacement des passagers; propriétés d’atténuation acoustique. Une série d’essais ont été mis au point pour mesurer les performances des nouveaux concepts soumis aux charges locales. Après ces essais, un seul matériau a été retenu pour le parement des panneaux de plancher, et deux matériaux d’âme se distinguaient favorablement des autres. Chacun de ces matériaux a servi à la construction de prototypes en prévision d’essais en vraie grandeur.

La conception détaillée du toit comportait elle aussi des considérations globales et locales. Encore une fois, les critères globaux ont été établis à partir du calcul des structures. À ceux-là s’ajoutait le critère des propriétés thermiques. Les principaux concepts ont donc été soumis à une analyse thermique. Les résultats de cette analyse ont mené au redimensionnement des parties constitutives du toit, de façon que les nouveaux toits offrent les mêmes propriétés thermiques que le toit existant, sans nécessiter d’isolation supplémentaire.

Les critères «locaux» de conception du toit avaient trait à l’assemblage des diverses composantes du toit et à la rigidité des montants de fenêtre. Des adhésifs ont été utilisés pour fixer le toit à la structure de l’autocar. Deux séries d’essais ont été mises au point pour vérifier la solidité de l’assemblage et la rigidité des montants de fenêtre. À la fin des essais, Prévost a choisi l’adhésif qui convenait à ce type d’assemblage. Seuls les montants de fenêtre en composite ont été soumis à des essais. Il avait été déterminé, en effet, que les montants en aluminium ne convenaient pas à cette région du véhicule, en raison de la corrosion galvanique entre le montant et le treillis latéral en acier inoxydable.

Les essais des premiers prototypes de montants ont révélé que les montants en composite n’avaient pas la rigidité des montants en acier soudé actuels. Cela a été attribué à un concept trop complexe ainsi qu’à des problèmes de fabrication, qui causaient une défaillance prématurée des montants de fenêtre. À chaque modification du concept, les performances de la pièce s’amélioraient. Toutefois, pour confirmer la faisabilité d’un montant en composite offrant une rigidité équivalente à celle des montants en acier actuels, un montant entièrement fait de fibre de carbone a été fabriqué et testé. L’expérience a été très instructive : le montant en fibres de verre n’est peut-être pas aussi rigide que le montant en acier actuel, mais le montant en fibres de carbone est plus rigide. Il est entendu que la version définitive du montant en composite sera composée de fibres de verre et de fibres de carbone, comme il avait d’abord été proposé. Il a en outre été convenu de poursuivre les travaux d’essai et de validation des montants de fenêtre au-delà de la fin de la phase II, dans le cadre du programme interne d’allégement des autocars mené par Prévost.

D’autres aspects de la conception de l’autocar (à part les composantes principales) ont été examinés au cours de la phase de conception détaillée. Il était crucial, pour le succès de n’importe lequel des nouveaux concepts, de bien choisir les adhésifs. Les membres du personnel de Prévost ont donc passé beaucoup de temps à s’informer sur l’utilisation des adhésifs, à acquérir de l’expérience pratique et à vérifier les propriétés physiques des adhésifs. Ils ont aussi examiné brièvement la possibilité d’installer des ceintures de sécurité, alors qu’ils étudiaient un nouveau rail de fixation des fauteuils. Les détails d’assemblage ont été incorporés aux nouveaux concepts, pour faciliter l’agencement des nouveaux concepts à la structure existante. Par ailleurs, les concepts ont été étudiés non seulement sous l’angle de leurs enjeux techniques, mais aussi de leur facilité de mise en oeuvre. Pour consultation future lors d’autres études de concepts allégés, un manuel de conception a été rédigé, qui expose tout le processus de conception.

Le processus de conception détaillée a finalement débouché sur un concept de plancher allégé. Deux matériaux d’âme se sont avérés répondre aux besoins du plancher et un matériau, aux exigences du parement. Des prototypes de panneaux constitués de chacun des matériaux d’âme ont été commandés et installés dans une maquette partielle du véhicule (voir la figure 6). Ces prototypes ont permis de faire un dernier contrôle des panneaux de plancher et ont donné au personnel de Prévost l’occasion d’examiner des techniques d’installation qu’ils pourraient appliquer à la chaîne de montage. Les deux concepts satisfaisaient aux exigences définies pour le plancher.

Le choix du concept de plancher définitif dépendra des coûts de production et des résultats d’une analyse acoustique, qui reste à faire. Il a été décidé de réaliser l’analyse acoustique non pas en laboratoire, mais à bord d’un prototype d’autocar en état de rouler. Le plancher comme tel présente de piètres propriétés acoustiques, comparativement aux propriétés acoustiques qui caractérisent le véhicule complet. Des essais en vraie grandeur devraient donner une représentation beaucoup plus précise de l’ambiance sonore à l’intérieur de l’autocar. Des prototypes de panneaux en vraie grandeur pourraient être installés dans un véhicule en vue d’essais sur route plus tard en 2003.

Au terme des travaux de conception détaillée du toit, aucun des concepts ne s’est détaché des autres comme étant le meilleur. Le module de toit à montants de fenêtre intégrés en matériau composite s’est avéré le plus économique et celui qui offrait les meilleures perspectives d’allégement, mais sa mise en œuvre supposait les dépenses d’immobilisation les plus lourdes. De plus, les essais des montants ont révélé que le moulage par infusion était loin d’être idéal pour des pièces d’une telle complexité. Des prototypes des deux concepts ont été commandés et ils seront installés dans la section de maquette où ont déjà été installés les concepts de planchers. Les prototypes de module de toit à montants de fenêtre intégrés et de toit en panneau sandwich sont présentés aux figures 7 et 8, respectivement.
Comme la qualité des prototypes de toit n’était pas à la hauteur, ceux-ci n’ont servi qu’à des fins de démonstration. Prévost et les fabricants des structures s’en sont aussi servis pour approfondir leur connaissance des procédés de fabrication, et de la manutention et de la fixation des pièces. La fixation du toit sur la structure en acier était sensiblement la même, quel que soit le concept. Mais dans le cas du toit en panneau sandwich, les modules de fenêtres devaient d’abord être fixés au panneau du toit avant d’être fixés à la structure. La production de ces pièces a été l’occasion d’acquérir une expérience précieuse, et de prendre conscience de nouveaux obstacles à la mise en œuvre des nouveaux concepts sur la chaîne de montage de Prévost.

FIGURE 6 : Installation dans une maquette des prototypes de panneaux de plancher

FIGURE 7 : Installation dans une maquette du module de toit à montants intégrés en composite

FIGURE 8 : Installation dans une maquette du concept de toit en panneau sandwich

Pour être en mesure de mieux évaluer le concept tout aluminium, Prévost a commandé une maquette de caisse d'autocar assemblée à l'aide du System 2000 à sa compagnie sœur, Säffle, en Suède. Son but était d'évaluer le concept avant d'intéresser ALCAN au projet. La maquette a permis à Prévost d'acquérir des connaissances inestimables sur les incidences de ce procédé d'assemblage sur la construction et le montage des véhicules. La maquette de Säffle est présentée à la figure 9.

FIGURE 9 : Maquette d'une section de l'autocar System 2000 de Säffle

Les connaissances acquises au cours de la phase 2 du projet seront utiles dans la mise au point des prochains véhicules de Prévost. Ainsi, les concepts de toit et de plancher allégés issus du présent projet serviront de composantes de base des modules appelés à former la structure du véhicule. Cette phase a coïncidé avec une modification importante de la portée du projet par rapport aux phases antérieures, car certains des nouveaux concepts modulaires peuvent être spécifiques à un certain type de véhicule (p. ex., des modules de toit différents peuvent être utilisés selon que l'on construit une autocaravane ou un autocar).

De plus, les concepts seront peaufinés afin d'optimiser la cadence de la chaîne de montage et de réduire le nombre de pièces à fabriquer. Ces mesurent se répercuteront jusqu'au service des achats, où l'on assistera à une diminution substantielle du nombre de pièces à acheter.

Afin de pouvoir appliquer les nouvelles technologies à la fabrication de petites séries, Prévost appelle l'industrie à mener des recherches sur de nouveaux procédés de fabrication et matériaux de pointe. Ces recherches devraient notamment porter sur des procédés de fabrication économiques applicables à la production de petites séries et de pièces en matériaux composites de grandes dimensions. Selon Prévost, le recours à de nouveaux matériaux et à de nouveaux procédés de fabrication ouvre la voie à un allégement substantiel des autocars. Beaucoup de travail a déjà été accompli en ce sens en Europe, mais l'Amérique du Nord tire encore de l'arrière.

Ces travaux de conception avancée, conjugués aux autres programmes internes d'allégement des autocars menés par Prévost Car contribueront grandement à renforcer la position de cette société parmi les grands constructeurs d'autocars d'Amérique du Nord. Le concept de toit n'est pas encore tout à fait au point, mais les spécialistes de Prévost poursuivront le travail à l'interne. L'entreprise envisage aussi d'autres initiatives très prometteuses pour la fabrication de véhicules allégés à partir des concepts issus de cette phase combinés aux nouveaux principes d'approche modulaire.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

ATTB	Advanced Technology Transit Bus
ECE	Economic Commission of Europe
FE	Finite Element
FEA	Finite Element Analysis
FRP	Fibre Re-inforced Plastic (Fibreglass)
ft.	Feet
g	Gravity
in.	Inches
kg	Kilograms
lb.	Pounds
LCC	Life Cycle Cost
mm	Millimetres
mph	Miles per hour
NABI	North American Bus Industries
SCRIMP	Seeman Composite Resin Infusion Moulding Process
3D	3 Dimensional
VARTM	Vacuum Assisted Resin Transfer Moulding

1. INTRODUCTION

Historically, the weight of intercity buses has steadily increased over the past couple of decades. This is true of Prévost Car buses with the exception of the past few years where increases in the weight of Prévost buses have been curbed. This “levelling-off” in weight is due to an extensive multi-year weight reduction program to offset the weight gains from additional equipment required as a result of ever increasing customer demands and to comply with newly introduced governmental weight regulations. In addition, Prévost Car, as a corporate entity, recognizes the importance of helping Canada reach its goals regarding ratifying the Kyoto Accord.

Part of the total Prévost weight reduction initiative is a three-phase advanced engineering project to develop lightweight intercity bus structural components. The first phase of this project, which was completed in January 2000 (see TP 13560E), resulted in the development of several lightweight design concepts for the roof, floor, and side truss components of the bus. The advanced engineering project has currently completed the second phase, which started in February 2001.

In Phase II, the most promising design concepts from Phase I were investigated in detail to determine the optimal design to be selected for detailed design, prototype development, and ultimately full-size vehicle prototype (Phase III).

Based on an evaluation of the three concepts in Phase I, it was decided that the Phase II study would focus on the floor and roof components. The side truss of the bus was not selected since it is the primary structural component in the bus and redesigning this component was considered to be too ambitious for the resources of this project.

The second phase project work began with two tasks: to evaluate the potential roof and floor design concepts, and to recommend which of these should be selected for detailed engineering design. Amongst other things, the potential designs were evaluated for weight, material cost, fabrication cost, process cost, and how effectively the components could be integrated into the current production line. In addition, the design concepts were evaluated against existing and previous lightweight bus designs in an attempt to identify effective ideas from successful designs or ineffectual ideas from failed designs. The details of this work is presented in Sections 4 and 5 of the report.

Following the first tasks, the detailed design was carried out on the selected design concepts. This work involved global structural analysis of the components; local analysis, design and testing of the components; and testing to validate both at a component level and at an overall global bus level. This is presented in Section 6.

The final task was the fabrication and assembly of prototypes of the new floor and roof components. This served as a final check on the manufacturability of the designs to ensure the successful development of lightweight intercity buses. The details of this work is presented in Section 7.

The goal of the Phase II advanced engineering project was to reduce the weight of the floor and roof structural components by 50 percent (without significant cost increases). Based on the current weight of the roof and floor, this translates into a weight savings of 720 kg (1584 lb.), 330 kg and 390 kg from the from the roof and floor, respectively. While this project is very important to Prévost, it is one of many internal projects currently under way at Prévost Car with an overall objective of further reducing the bus weight by an additional 150 kg (330 lb.) per year. A summary of Prévost Car's overall weight reduction program is presented in Section 2.

2. SUMMARY OF PRÉVOST CAR'S OVERALL WEIGHT REDUCTION INITIATIVE

The Phase II advanced engineering project, as described in this report, is just one of many projects being undertaken by Prévost Car in its overall weight reduction program. The goal of this program is to reduce the weight of their buses by an additional 150 kg (330 lb.) per year over and above the Phase II weight reduction objective. This is being achieved through identification and re-engineering of selective bus components/parts that are targeted for weight reduction potential.

A summary of the work already carried out to reach this goal is provided in Table 2.1. This table identifies components that have been and are currently being re-engineered for weight reduction along with the weight reduction achieved (or predicted) for each component/part.

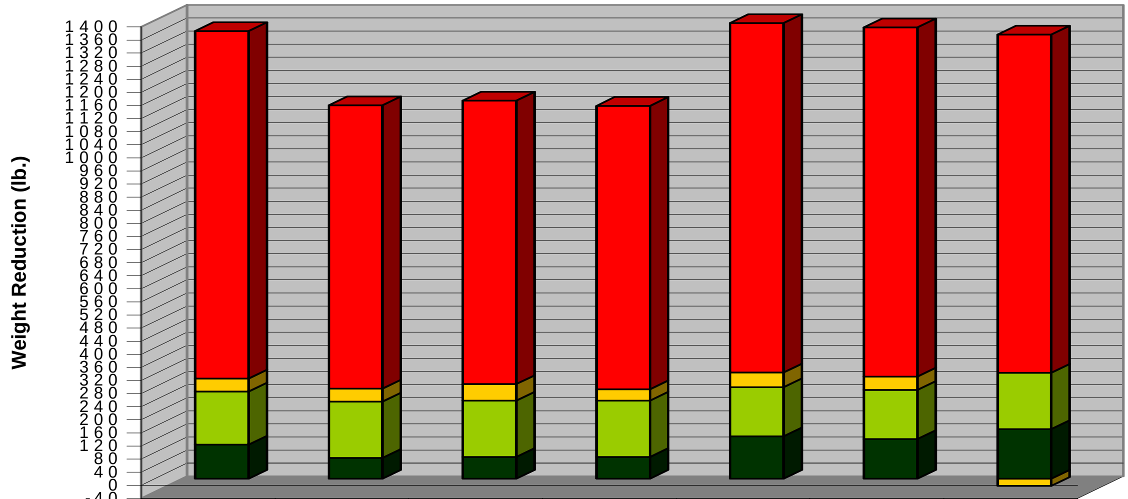
Table 2.1: Summary of Prévost Car's Overall Weight Reduction Program

Weight Reduction Project	Weight Saved
Parcel Rack	18 kg
Mantex Luggage Comparment Floor	59 kg
Thinner Passenger Floor	32 kg
Passenger Seats	350 kg potential
Brake Components	66 kg
Drive Axle	28 kg potential
Transmission	102 kg
Pulltruded Side Panel	64 kg
Bumpers (flexible polyurethane over and extruded aluminum beam)	50 kg
New Starter	12 kg
Super Single Drive Tire	50 kg potential
Lighter Engine (Cummings - Detroit Diesel - Volvo)	190 kg potential

To date, the weight savings that have been realized and put into production are shown in Table 2.2. The information is presented based on vehicle model. The complete range of Prévost buses are included in the table.

With the long-term goal of reducing weight by 150 kg/year over the next 10 years, Prévost Car will be targeting other areas of the bus weight reduction.

Table 2.2: Implementation of Short-Term Weight Savings by Prévost Vehicle Model



	X5	W5	WE	W0	H345	H341	VIP45
In Progress	1,062	866	866	866	1,067	1,067	1,033
To be Studied Further	39.2	39.7	50.7	34.7	45.5	40.5	-22.1
Introduced 2003	162.1	172.1	172.1	172.1	150	150	172.1
Introduced 2002	0	0	0	0	0	0	0
In Production	104.1	63.1	66.1	66.1	129	121	151.1

3. OBJECTIVE OF THE PHASE II PROJECT

The objective of second phase of the advanced engineering project was to determine the most efficient methods of production of lightweight intercity bus structural components (in terms of weight and costs) and then based upon these methods, to design and produce prototypes of these components. At the conclusion of the project, Prévost Car management had to be convinced of the viability of the new designs before implementation into production vehicles could commence.

The philosophy behind the design process was to select the best material for the application, thereby aligning Prévost with new automotive trends. The vehicle was still to be designed to have a 15-year, 3.2 million kilometre operating life without any increase to the current cost. Flexibility on the assembly line is paramount to Prévost's manufacturing process, and the use of offline sub-assemblies and Just-In-Time supplier requirements are keys to maintaining this flexibility. The global effect on the Prévost organization had to be considered as the various designs progressed from concept through to prototype.

4. LITERATURE STUDY AND PRÉVOST PRODUCT EXPERT INPUT

In order to select the most efficient designs, data was collected from various sources for the evaluation process. These sources included in-house Prévost experts, fabricators, literature, and research establishments.

Data was collected on types of materials, methods of fabrication, design requirements and constraints, process requirements and limitations, cost of materials, cost of fabrication, and cost of manufacturing. In addition, information was gathered on lightweight bus designs that had been previously conceived. This data was used to evaluate the possible design concepts and to determine the concept to be used for the detailed design.

The results of this data collection process is presented in sections 4.1 and 4.2.

4.1 CURRENT INDUSTRY LIGHTWEIGHT BUS DESIGNS

Information was gathered on lightweight concepts that have been previously tried in the bus industry. The purpose of this was to examine these designs for success in an attempt to demonstrate viability of the Phase II designs.

It was found that lightweight bus concepts were on the market, though mostly in Europe. Four promising designs were examined ranging from all-composite monocoque structures to modular hybrid designs utilizing composite sandwich panels attached through aluminium extrusions. Although the lightweight designs were not completely applicable to the Prévost planned production methods for the new lightweight structure, considerable information on fabrication techniques and state-of-the-art material usage was obtained.

A summary of four lightweight bus designs is presented in the following sections. In each summary, the design is described followed by a discussion on the design features that could be utilized in a Prévost lightweight bus.

4.1.1 Advanced Technology Transit Bus

The Advanced Technology Transit Bus (ATTB), as seen in Figure 4.1, was developed under a federal grant from the United States Federal Transit Administration. Grumman Northrop was contracted to develop and produce the prototype for a lightweight, low-polluting bus for urban transit operation. The project began in 1994 and ended in 1999. Over the five-year period, six prototypes were produced and tested. Structural sandwich panel construction and an advanced hybrid power train were developed for the project. The final prototype weighed 21,800 lb., roughly 30 percent lighter than a conventional bus.

The structure of the ATTB consists of four major assemblies: the roof, the floor and sides, and two window sections, which are bonded together. The flat areas of the walls, floor, and ceiling consist of 2-in. thick sandwich panels of E glass fibre over closed cell Klegecell PVC foam core. A matrix of Dow Chemical Companies 441-400 Derakane epoxy vinyl-ester resin was used for benefits such as creep resistance and room temperature curing. More complex areas were constructed from dry glass preforms. Preforms and assemblies were vacuum bagged and infused with resin in a proprietary vacuum-assisted resin transfer moulding (VARTM) process.

The floor/side assembly is a single piece 37.5 ft. long, 8.5 ft. wide, and 3.5 ft. deep. The "bathtub" shape resulted in higher moment of inertia effects for bending resistance. Exceptionally robust, the hull has withstood a simulated impact from a 4,000 lb. car at 25 mph, sustaining only cosmetic damage.

Figure 4.1: The Advanced Technology Transit Bus (ATTB)
(Photo courtesy of the United States Federal Transit Administration)

The ATTB was tested at the Altoona Bus Research and Testing Centre and on the streets in four major US cities. In all tests the structure of the ATTB met all design requirements for stiffness and strength. Structural delamination problems occurred on two of the prototypes between the two rear wheel wells at suspension connection points. This failure was determined to be the result of human errors during initial fabrication and not a design flaw.

Although not directly related to the Prévost weight reduction program, other features of the ATTB are worth noting. The ATTB utilized lexan rather than glass for the passenger windows, to save weight. Problems with adhesion of the windshield to the front cap were encountered on some of the prototypes, resulting in water leaking into the bus. The seats in the ATTB were cantilevered off of the sidewall to give more leg and storage room. It was felt that the composite floor covered with a textured paint would require painting every year, so the current rubber coverings were preferred.

The ATTB modular structure would be suited to the current Prévost line and is another example of the use of composite sandwich panel construction and bonding in bus construction.

The ATTB testing program ran for 35,000 miles, in climates from hot and dry in Phoenix to humid and cold in Boston, without any structural degradation. The ATTB had no under floor baggage compartments and the "bathtub" type floor/side structure was chosen, greatly improving the longitudinal bending moment of inertia of the bus.

4.1.2 *NABI CompoBus*

The North American Bus Industries Inc. (NABI) CompoBus is a derivative of the ATTB. The prototype was developed by TPI Composites Inc. of Rhode Island using the patented SCRIMP (Seeman Composite Resin Infusion Moulding Process) and unveiled in February 1999, demonstrating its ability to manufacture a bus with an all-composite chassis.

The CompoBus is built in four sections: the floor and sides, which act as the chassis, the front end, the rear end, and the roof section. These sections are bonded (instead of mechanically fastened together) to form a one-piece integral chassis/body unit, as seen in Figure 4.2. The body of the bus is a sandwich panel of glass fibre over end grain balsa core utilizing a vinyl-ester resin matrix delivered via the SCRIMP. According to NABI, collision damage is easy to repair. The damaged area is cut out and a replacement section is trimmed to fit. The panel is then bonded in place using conventional hand lay-up techniques. The seams can then be sanded and the area painted to mach the remainder of the body.

Figure 4.2: NABI CompoBUS One-Piece Composite Structure
(Photo courtesy of North American Bus Industries, Inc.)

The prototype CompoBus (as seen in Figure 4.3) is a 40 ft. urban bus weighing 22,000 lb. This is 7,000 lb. lighter than a conventional bus. NABI expects the CompoBus to cut expenses for fuel, tires and brakes by as much as 25 percent in addition to yielding significant corrosion repair savings. In small unit production the CompoBus is expected to cost 15 to 20 percent more than a conventional bus, but in full-scale production, the price of the CompoBus should approach that of its conventional counterparts.

Volume production of the CompoBus in 40 ft. and 45 ft. lengths began in June of 2002 in NABI's newly built Hungarian plant. The plant was specifically built to construct the two CompoBus models. The first bus delivered to the North American market went into service this year with the city of Phoenix Public Transit Department.

Figure 4.3: Completed NABI CompoBus
(Photo courtesy of North American Bus Industries, Inc.)

In the context of the Phase II project, the CompoBus demonstrates that there is a significant weight savings with the use of composites, roughly 32 percent in this application. As well, a very high strength-to-weight ratio can be achieved with a VARTM process such as SCRIMP.

The monocoque construction technique would not be suited for the Prévost production line due to the need for an entire line redesign, but the idea of modules could be implemented. Roof and floor sections are modular, which gives merit to the sub-assembly approach. Similar to the ATTB, the floor/side combination as one unit takes advantage of the "bathtub" effect, greatly increasing the moment of inertia of the floor. Although the CompoBus is an urban bus (without baggage compartments under the floor), some concepts of its design could be applied to intercity buses.

4.1.3 *BOVA Magiq Bus*

The BOVA Magiq bus is a module-based hybrid material design that takes advantage of modern materials and manufacturing processes. Extensive use of sandwich panels in the roof and end cap result in a lightweight, easy-to-assemble structure. Another innovation applied in the design is the incorporation of structural composite roll bars at each end of the bus. The roll bars allow the design to meet Economic Commission of Europe (ECE) R66 rollover requirements and allow for easy attachments of the end caps.

Magiq is built in a number of modules that are fully completed before mating. There are eight modules that make up the bus structure: mid-section, front axle section, rear axle and engine section, side wall sections, toilet section, roof section, rear section, and front section. Mating of components is achieved by bolting or bonding; no welding other than that to assemble the front and rear sub-frames is used. The eight modules are broken out and shown in Figure 4.4

The roof section is a sandwich composite panel consisting of 30 mm thick structural foam with aluminium skins of 1.2 mm thickness. The edges of the roof panels are reinforced using aluminium extrusions specifically shaped with respect to interior fixation. The sandwich panels are made by the Alusuisse Airex vacuum bag technique. The roof section is built on a jig offline. The air conditioning system is fitted and the structure is flipped over for installation of the interior trim and luggage racks. The roof module is affixed to the structure by use of an elastic bonding system in combination with mechanical fasteners.

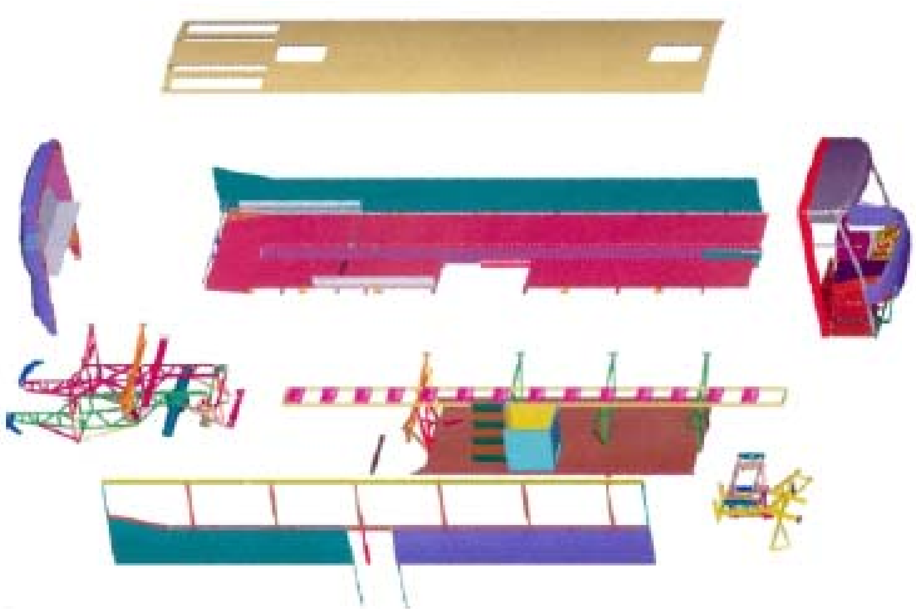


Figure 4.4: The BOVA Magiq Structural Component Modules
(Photo courtesy of ALCAN Inc.)

The front and rear end modules are 3D-FRP sandwich composite shells. The sandwich modules consist of foam cores ranging in thickness between 20 and 30 mm and FRP face layers of long randomly oriented fibres. Both front and rear modules are completely assembled offline before connection to the rest of the structure. The front-end assembly consists of the driver's compartment, entrance steps, and one-piece windshield. The rear end section is complete with exterior lights, interior trim, and a rearmost set of seats. The rear section is attached by bonding to the upper part of the vehicle and mechanically fastening to the lower portion. The front section is assembled out of a steel frame on which the composite roll bar is attached by means of a bolted construction. After the steel frame is covered with FRP parts, the foam core sandwich front module is bonded to it along with the aluminium A-pillars. The front roof section is then bonded to the roll bar. With the final attachment of the windshield, the structural module is complete with the roll bar forming a ring around the cross section of the bus.

The composite roll bars, made by ALCAN Composites, are what give the BOVA Magiq its required strength to meet the R66 rollover requirements. Full-scale vehicle testing has been performed on the Magiq by the Cranfield Impact Testing Centre in England. During the course of this project, team members visited the centre and had the opportunity to speak with staff. They confirmed that composite roll bars are in fact the best approach to rollover protection in terms of strength and minimization of weight compared to steel. The BOVA Magiq undergoing the R66 rollover test at the Cranfield Impact Testing Centre is shown in Figure 4.5.

Figure 4.5: R66 Testing of BOVA Magiq Coach at the Cranfield Impact Testing Centre

(Photo courtesy of ALCAN Inc.)

The front and rear axle assemblies are welded from square section steel tube, assembled offline and fitted with all drive train, steering, and suspension components before attachment to the bus structure. The side wall is a conventional steel structure as well. However, the prototype vehicle utilized an aluminium side wall that was abandoned for steel because of lack of required stiffness.

The remaining modules are completely assembled before becoming part of the bus. The production process is designed so that those assembling the vehicle are always working in a comfortable and natural position. The floor section, for example, is assembled upside down and fitted with all electrical wires and plumbing, then flipped over to be trimmed and fitted with seats. Similarly the roof module is flipped to ease assembly of air conditioning and interior.

BOVA began production in 2000 with an estimated production volume of 160 buses for the year. For the first two production years the Magiq was to be offered in a one length and one height model. BOVA expected the cost of the Magiq to be 10 to 15 percent higher than its conventional bus design, the Futura. No information was found as to whether this goal was met or how the Magiq has held up under operation. A completed BOVA Magiq coach is shown in Figure 4.6.

Figure 4.6: Completed BOVA Magiq Coach

(Photo Courtesy of BOVA)

The Magiq bus design again demonstrates the feasibility of the hybrid approach and the use of lightweight materials such as aluminium and composites in bus construction. The use of composites in the sandwich panels and roll bars give a high strength-to-weight ratio, strong enough and stiff enough to pass ECE R66 rollover requirements. Bonding aluminium or steel to a composite panel was also shown to be possible. The notion of offline pre-assembled large structural modules could greatly reduce assembly time and could be implemented in a Prévost production line. Smaller modules can be manoeuvred or rotated into a safe working position, reducing work-related injuries. This concern was raised with the current Prévost process where at times workers are working above their heads or in cramped spaces, greatly increasing the chance of an injury.

4.1.4 D-Bus

The D-Bus body concept, owned by Volvo, uses a hybrid approach for coach design. The body tube is an integral assembly of extruded aluminium profiles that are bonded together with sandwich panels and windows. After the front and rear sections are glued to the ends of the tube, the whole body forms a closed double shell structure. With this kind of assembly, the original strength of the aluminium is maintained since there are no welded, bolted, or riveted connections. A completed D-bus coach is shown in Figure 4.7.

Figure 4.7: Completed D-Bus Coach
(Photo courtesy of Volvo)

The cornerstones of the new bus body are strong longitudinal beams located at both the lower and upper corners that are continuous through the whole length of the bus. The roof structure consists of transverse aluminium profiles at each window pillar with composite sandwich panels between each pillar. A similar concept is used for the floor. Window glass is circumferentially edged with an aluminium profile and attached to the side wall at the upper corner profile, window pillars, and along another continuous longitudinal profile running under the windows at the mid-height of the bus.

The body assembly consists of joining large modules: floor, walls, roof and end caps. During final assembly, the modules are glued together along their seams, with the final addition of the windows, which are glued in place to complete the structure.

The D-Bus body concept is for the body alone. This structure is meant to be placed over top of an independently constructed chassis as seen in Figure 4.8. This is very different from the Prévost design, yet the D-Bus demonstrates proof of concept. The notion of modules, which could be constructed simultaneously offline then assembled on line, could be implemented into Prévost production. The concept has also shown that the connection of aluminium extrusions to sandwich panels with hybrid approach of an adhesive alone is sufficient without the need for any mechanical fasteners. The aluminium extrusion/sandwich panel combination offers great strength-to-weight characteristics as well as noise insulation, vibration control, and thermal isolation characteristics.

Figure 4.8: Example of D-Bus Body over Chassis Concept
(Photo courtesy of Volvo)

4.2 PRÉVOST PRODUCT EXPERT DESIGN CHECKLIST

A series of meetings and discussion sessions were conducted with Prévost product experts in order to determine the important considerations for any new lightweight bus design.

As discussed in Section 1, the roof and the floor components of the bus were chosen for detailed design in this phase of the project. Therefore, the data collected from Prévost staff was focused on the lightweight design considerations for these components. From the collected data, a checklist of requirements was developed for the roof and floor components. This checklist identified the items that would have to be addressed in the designs and is provided in Table 4.1.

Some of these items refer to specific design parameters while others refer to design considerations (i.e., components that may not be directly designed as part of the roof and floor but must be considered in the design).

Table 4.1: Design Checklist for the Floor and Roof

Floor Design Checklist		Roof Design Checklist	
Item	Description	Item	Description
1	Match current local stiffness/deformations	1	Match current local stiffness/deformations
2	Natural frequencies > Lower Limit	2	Natural frequencies > Lower Limit
3	Slip resistance surface	3	Rollover strength considerations (40% of R66)
4	Contribute to overall bus stiffness	4	Parcel rack stiffness incorporation
5	Soundproof/acoustic properties	5	Overall bus stiffness contribution
6	Incorporation central tunnel	6	Window integration
7	Incorporation air ducts	7	Maintain aesthetics (round corners)
8	Seat connections/crash loads	8	Incorporate stiffness into overall bus stiffness
9	Seat track insert	9	Fabrication time
10	Seat track/crash loads	10	Material cost
11	Connection to truss & subframes	11	Tooling cost
12	Baggage compartment support reinforcements	12	Material weight
13	Shoe/heel punch through	13	Hardware weight
14	Fabrication time	14	Overall weight
15	Material cost	15	Attachment details
16	Tooling cost	16	Waterproof design
17	Material weight	17	Fire retardant material
18	Hardware weight	18	Fabrication process/health issues
19	Overall weight	19	Process as a subassembly
20	Attachment details	20	Process flexibility
21	Fire retardant material	21	Thermal effects on design
22	Incorporation of floor covering	22	Thermal insulation properties
23	Fabrication process/health issues	23	Details of attachment to rear cap
24	Process as a subassembly	24	Attachment to front structure/rollbar
25	Access of wiring harness in-service	25	Corrosion resistance
26	Process flexibility		
27	Can screws be used effectively		
28	Thermal insulation properties		
29	Details of attachment to rear		
30	Details of attachment to front		
31	Corrosion resistance		
32	Details of attachment to side and seat track		

5. SELECTION OF ROOF AND FLOOR CONCEPTS FOR DETAILED DESIGN

When the advanced engineering project to develop lightweight buses was initiated at Prévost, one of the prime requirements was that the new designs be implemented into the current process without significant changes. This necessitated that the approach be more of an evolutionary one rather than a high-risk revolutionary one. As noted in Section 1, this approach led to the decision not to tackle the design of a lightweight side truss, since this would be a significant undertaking that would potentially require extensive infrastructure changes. Consequently, the project focused on the bus floor and roof structure, which could be more readily isolated from the other manufacturing processes and thus not require significant capital investment.

The selection of the design concepts for the roof and floor was based on the data collected as described in Section 4. The most important of these was the information gathered directly from Prévost staff. These product experts have intimate knowledge of the current state of the art in bus and automotive manufacturing methods. This knowledge along with the other gathered data was used to select the preferred design concepts.

5.1 INITIAL DESIGN CONCEPTS FROM PHASE I

From the results of the Phase I work (TP 13560E), three design concepts were chosen as potential candidates for possible development of lightweight bus structures. The first concept was a hybrid design where metals, foams, and composite materials are combined in the design of the structural components. In this type of design, the philosophy is to select the best material for the intended application. The possibility of utilizing a hybrid concept has only been realized in recent years due to the significant advancements in bonding technologies that permit the structural joining of dissimilar materials. The Phase I study results showed this design as being the most promising for significant gains in life cycle costs (LCC).

The second concept was an all-aluminium design strategy. Prévost Car recognizes the potential for significant LCC savings with using a lightweight material such as aluminium. However, based on previous experience with aluminium, there were concerns with corrosion problems with this material. There were two distinct variations in this type of design: an all-welded aluminium framework, or an all-fastened aluminium framework.

The third concept was a variation of the hybrid concept with the distinction that the roof be constructed solely from composites. The roof structure can be fabricated in a monocoque fashion either in modules or in one piece. Composite manufacturing processes are designed specifically for this type of fabrication.

5.2 ELIMINATION OF POTENTIAL METHODS

During the data collection process, it became clear that one of the proposed concepts would not be viable due to the high cost of implementation. This was one variation of the all-aluminium concept. The basis for the all-aluminium concept was a material substitution from the current steel framework to an aluminium frame. There were two distinct fabrication methods available with a complete substitution to aluminium. The first was a welded frame and the second a fastened frame using a system similar to the ALCAN/Alusuisse and/or the Säffle Karosseri System 2000 systems.

Similar to the current steel structure, an all-aluminium-welded strategy would involve a substantial amount of welding. While aluminium welding is not an uncommon practice (the most spectacular example could be the all-aluminium space frame of the Ferrari Modena fabricated by ALCOA.), implementing it at such a large scale would be very costly. The aluminium would have to be stored separately from the steel currently used in the bus to eliminate contamination from "steel dust". This storage area would have to be dry and the aluminium would have to be brought to room temperature just before welding. This might require additional storage space at Prévost, which is currently at a premium. The aluminium would have to be cleaned before welding with an 8-hour time frame to weld before oxidization reforming would require cleaning again.

In terms of the actual structure, there could be significant distortion as a result of the welding process, with the welded material losing some its strength. This would require heat treatment to regain material strength, which would be costly on the large parts fabricated for the bus. In addition, due to the loss of strength, large safety factors would be required for aluminium joints. This would have the potential of increasing member sizes and thus weight.

It is important to note that these issues do not eliminate the possibility of using aluminium in the lightweight designs. In contrast, aluminium usage will most likely be increased in the new designs. However, other methods of joining rather than welding will be employed. In particular, as discussed in Section 5.3.1, the all aluminium–fastened concept will be evaluated against the other potential design concepts.

5.3 SELECTED DESIGN CONCEPTS

5.3.1 *All Aluminium–Fastened Concept*

The basis for the all aluminium-fastened concept was a framework of aluminium extrusions connected at the joints through mechanically fastened gusset plates. This is presented in Figure 5.1, which shows the ALCAN/Alusuisse and Säffle System 2000 method.

This type of structure offered the following advantages:

- Flexibility for the motor home options;
- Minimum tooling;
- Precise structure with no welding distortion; and
- ALCAN/Alusuisse experience available for consultation.

The disadvantages of this type of structure were as follows:

- Potential for galvanic corrosion in crevices;
- Assembly is labour intensive; and
- High thermal conductivity of aluminium can create problems with condensation.

The unknowns with this type of structure were the resistance to rollover and the overall stiffness of the assembled structure.

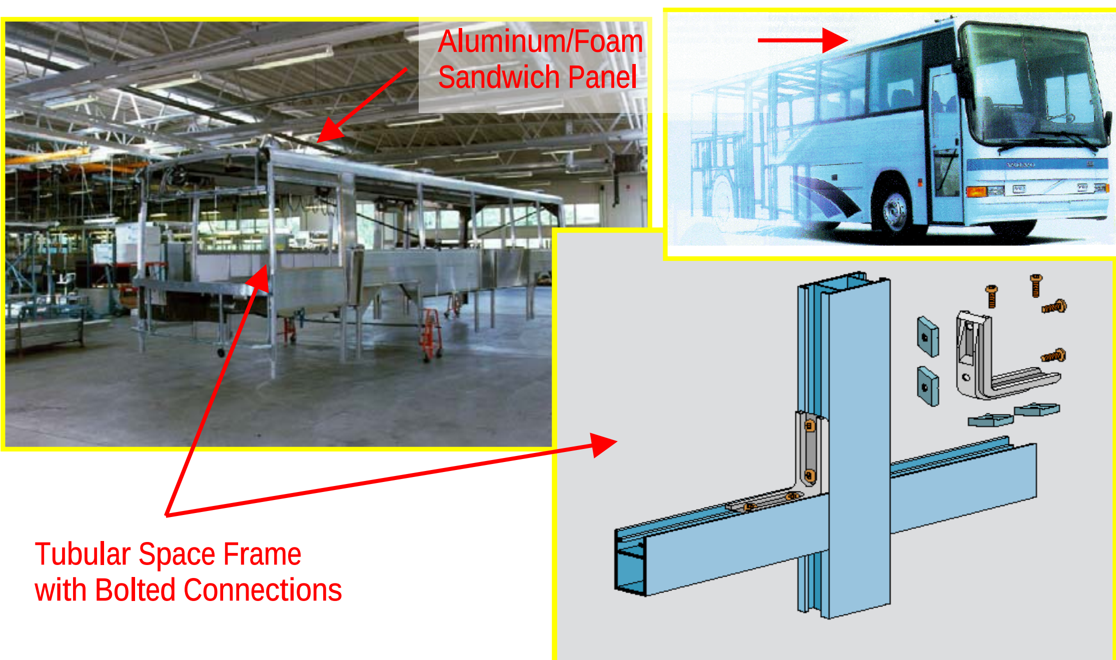


Figure 5.1: Example of the All Aluminium–Fastened Design Concept
(Photos courtesy of Säffle Karosseri AB and ALCAN Inc.)

5.3.1.1 ALCAN Study Results

To determine the viability of the all aluminium-fastened concept, ALCAN initiated a study to compare the strength and stiffness of a Prévost Car intercity bus structure fabricated using this concept. Prévost released the finite element model of its H3-45 in order for ALCAN to perform the study.

The proposed vehicle to be studied was an integral structure similar to what is currently used on the H3-45. The major difference was that the proposed structure was to be fabricated from aluminium extrusions and sandwich panels rather than welded steel as is used on the H3-45. The structure would be self-supporting without the need of additional frame members as is common in most European bus designs, which are typically body-over-chassis designs. The exterior was to be fabricated from either aluminium or composite body panels.

Outside the structural considerations, questions concerning the robustness of this fastened concept have been raised and will have to be addressed with this type of design. Important areas of concern are corrosion of the aluminium (crevice, galvanic, and atmospheric) and maintaining a class A surface finish on the exterior of the vehicle throughout its operational life. Although this concept has been utilized on many European designed and operated coaches, its application in a North American operating cycle and climate is a major area of concern to Prévost Car.

As noted above, aluminium corrosion issues were of major concern to Prévost and had to be addressed by ALCAN during this study. ALCAN corrosion specialists examined older Prévost vehicles as well as vehicles from other bus manufacturers to familiarize themselves with the corrosion issues of the current designs. ALCAN specialists proposed solutions to increase the performance of the study vehicle. These solutions can also be used to increase the performance of the current vehicle.

The results of the ALCAN study show that an aluminium structure can be designed that matches the stiffness of a current Prévost coach. The potential weight saving of such a design would be 559 kg for a complete bus when considering only the modified components; however, it comes with an associated cost increase of 13%. It is expected that the costs will decrease after completion of a much more detailed investigation that would also see the new components developed to serve multiple functions in the vehicle, thereby reducing the number of parts needed as well as costs. Prévost is continuing to work with ALCAN to further develop this concept. The objective of this further work is to address corrosion concerns when using aluminium for major components in long-life applications such as coaches.

5.3.2 Hybrid Concept

From the information gathered in Phase I, the concept that exhibited the most promise for lightweight components was the hybrid concept. This was reinforced in the initial stages of Phase II based on the bus performance requirements as identified through discussions with Prévost product and engineering experts, and also from the information gathered regarding the current state of the art in bus and automotive manufacturing processes.

The hybrid approach utilizes a combination of different materials that satisfy the requirements of the specific location on the structure. The materials are bonded together using structural adhesives or mechanical fasteners. While both fastening methods are used in industry, it is quite evident that the most recent trend in bus manufacturing is to use the bonded approach.

The information gathered from the literature review and discussions with ALCAN reinforced the merit this approach. Bus manufacturers such as BOVA are now designing and building buses using the state-of-the-art hybrid approach using bonded sandwich panels. In addition, major automotive manufacturers such as Aston Martin, Mercedes, and Lotus all are now starting to utilize this process. The hybrid approach spans the entire spectrum of new vehicle design and is emerging as one of the most significant design processes for the future. However, since different materials are fastened together, considerable study must be given to problem of corrosion in order to guarantee the long life requirement of a vehicle such as a bus.

The hybrid design selected for the lightweight bus structure is composed of a series of different structural components such as sandwich panels, aluminium extrusions, composites, and steel as shown in the sketch of Figure 5.2. This plot shows the overall bus cross section. The basis for the proposed hybrid design is presented in Sections 5.3.2.1 and 5.3.2.2 along with the details of each different type of design considered for the roof and floor.

5.3.2.1 Roof Design Concept

In the selection process for the roof designs, it was necessary to look at the role of the roof and decide which type of structural components would offer optimal weight savings, while satisfying the structural and functional requirements. The major roles of the roof structure were defined as follows:

- Provide overall bus longitudinal torsional stiffness/strength;
- Provide lateral bending stiffness/strength between the window posts;
- Provide overall bus longitudinal bending stiffness/strength;
- Provide bending stiffness to support the parcel rack load;
- Provide stiffness for rollover protection;
- Provide passenger protection from the outside environment (rain, snow, cold temperature, etc.); and
- Provide enough of a stiffness-to-weight ratio for resulting natural frequencies in bending and torsional to be above operating frequencies.

The sandwich panel design was ideal for this purpose. The overall bus longitudinal bending strength is partially carried in the roof through in-plane compressive forces. While the skins are very thin, the overall cross-sectional area of the skins provides significant structure for this load. A sandwich panel offers high torsional and more local bending stiffness for a very little weight penalty as compared to other structures. The upper and lower skins carry the loads mostly through in-plane tension and compression, while the foam is designed to carry the shear forces between the skins.

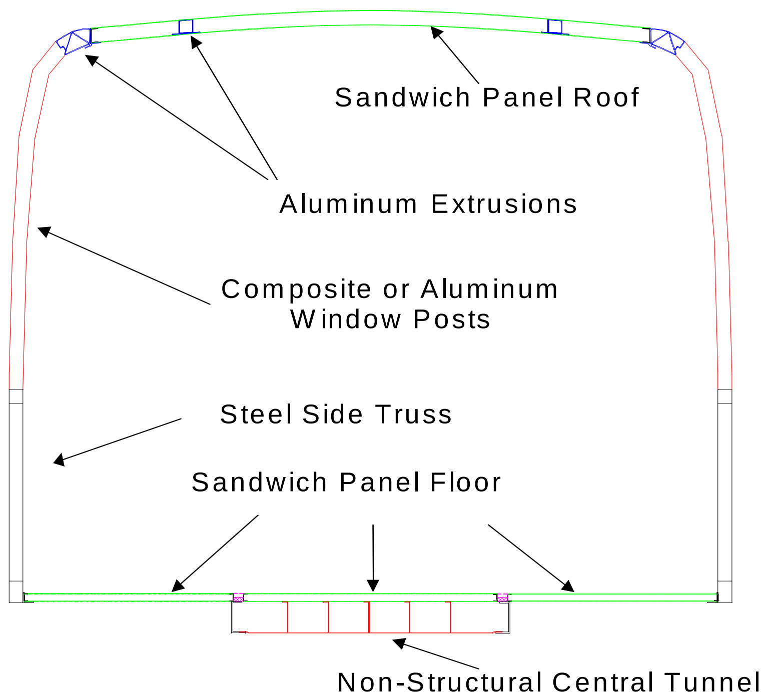


Figure 5.2: Lightweight Bus Structure Utilizing the Hybrid Approach

Based on the required parameters, several designs were selected for the roof structure. Plots of the lightweight roof designs are presented in Figure 5.3 and Figure 5.4. All designs had several common features:

- A sandwich panel to carry the roof structural load;
- Inboard embedded extrusions in the sandwich panel to carry the parcel rack loads; and
- New (composite or aluminium) window posts.

In the first design (Figure 5.3), the roof sandwich panel was constructed in one piece and utilized two outboard extrusions at the longitudinal edges to join to the top of the window posts. Common to all hybrid designs were the two imbedded inboard extrusions (see upper expanded view in the figure) for connection of the parcel rack for the coach models. Since the inboard extrusions are imbedded in the sandwich panel they would also be very effective for the motor home models as interior attachment points since they do not protrude into the interior space. Examples of the potentially different variations of this design are shown in Figure 5.3, where one side of the bus has three window post modules and the other side has one.

The transition from the top of the window posts to the roof top had to be of sufficient strength and stiffness to evenly distribute the concentrated window post loads to the sandwich panel.

Depending on the chosen design, this would be either through an aluminium extrusion running along the outside edge of the roof top or through a stiffened section along the edge of the composite sandwich panel where the window post is attached. This is shown in the lower expanded view in Figure 5.3.

The advantages to the design in Figure 5.3 were as follows:

- Flexibility for the motor home options;
- Pre-assembly of the complete roof, including parcel racks and interior finishing; and
- Simplification of the window posts using optimized composite materials.

The disadvantages of this type of design were as follows:

- Equipment required for handling of large parts;
- Difficulty of matching the stiffness of steel window posts; and
- Complexity of bonding large components together.

The unknowns with this design were the stiffness of the new (composite or aluminium) window posts, the stiffness of the glued joints, and the selection of the proper adhesive.

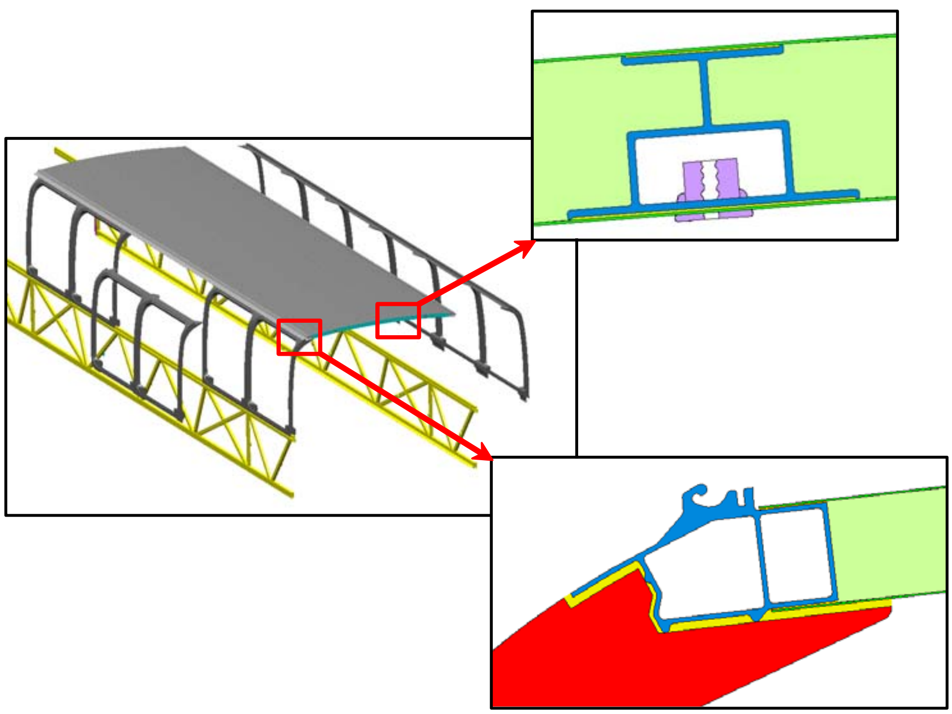


Figure 5.3: Proposed Lightweight Roof Design of Full-Length Sandwich Panel with Composite Window Posts or Modules

In the second design (Figure 5.4), the entire roof section, including the window posts, was fabricated as a one-piece section. This part would be fabricated from composites using an infusion process as demonstrated in Figure 5.5. The imbedded inboard extrusions for connection of the parcel rack would be included in the lay-up of the roof module and therefore be built into the final part. As shown in Figure 5.4, this design offers the flexibility of manufacturing in varying roof section lengths. The plot shows roof sections can be fabricated in sections with three window posts and five window posts. One configuration of this design would be a one-piece roof including all of the window posts. This one-piece part would not require joints in the roof, thereby eliminating a potential source of water leaks.

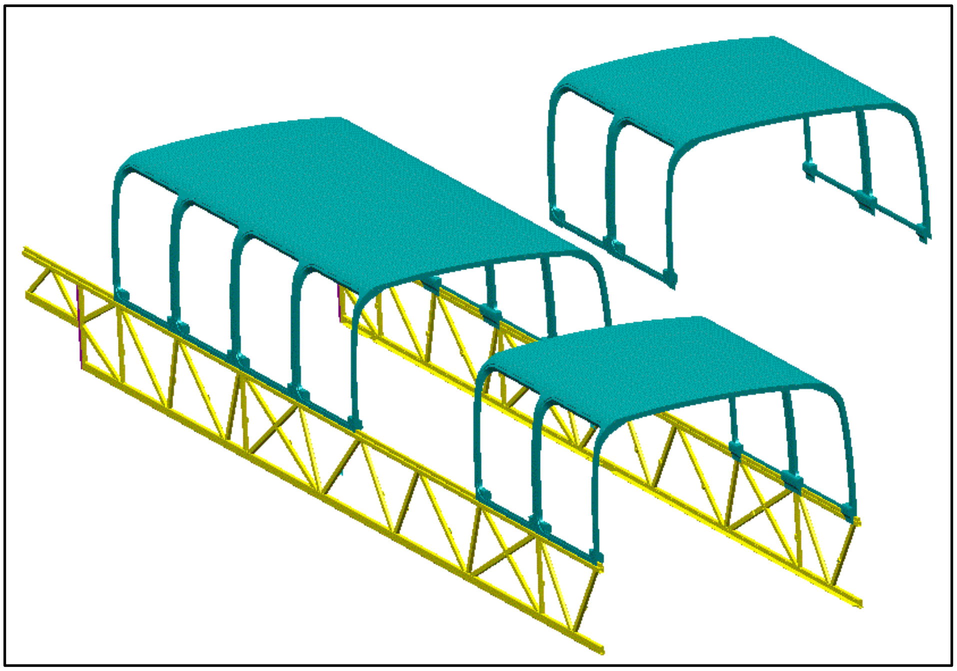


Figure 5.4: Proposed Lightweight Roof Modular Design of Complete Roof and Window Post Sections of Varying Length

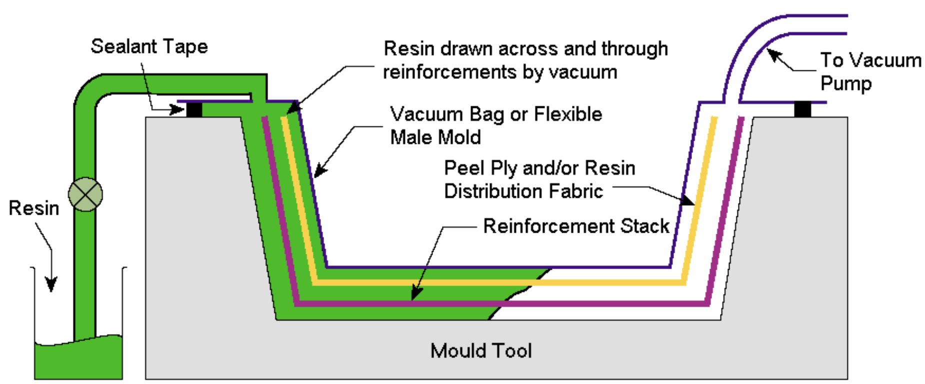


Figure 5.5: Sketch of Infusion Process for Manufacturing Composite Panels

The advantages to the design in Figure 5.4 were as follows:

- Potential for good rollover performance; and
- Pre-fitting of interior finishing before attaching to vehicle.

The disadvantages of this type of design were as follows:

- Lack of flexibility for the motor home; and
- Joints in the roof have the potential for water leaks (not applicable in the case of a full-length roof module).

The unknowns with this design are the same as the design in Figure 5.3: the stiffness of the composite window posts, the stiffness of the glued joints, and the selection of the proper adhesive.

Regardless of the chosen design, it was proposed that the window posts be fabricated from either composite materials or aluminium. In order to reduce the weight of the posts, it was necessary to make a change from the currently used material, steel. One significant consideration with using aluminium was at the bottom of the window post (aluminium) where it is attached to the top of the side truss (stainless steel). It was felt that the potential for galvanic corrosion was likely at this location; therefore, FRP posts will be studied in the detailed design of Section 6.

The design of the composite window posts had to be anisotropic in order to optimize the stiffness and mechanical properties for directional purposes. This would require detailed stress analysis and testing to ensure the new design matched the current stiffness.

From the analysis work performed, it was proposed that the parcel rack casting not be incorporated as a structural member. A series of analyses was performed to determine the additional stiffness that the parcel rack could provide to the roof stiffness; however, it was found that with the current configuration, this was negligible. If the casting could be attached at a lower position on the window post, it would be much more effective. Unfortunately, this posed aesthetic and functional problems in the interior space of the bus just above the passenger heads. For this reason it was decided to leave the parcel rack in its current configuration.

5.3.2.2 Floor Design Concept

Similar to the design of the roof structure, the first step in selecting new floor designs was to identify the major roles of the floor:

- Provide overall bus bending stiffness/strength;
- Provide overall bus torsional stiffness/strength;
- Provide local strength/stiffness for passenger loads; and
- Carry passenger loads to the side truss.

The sandwich panel design was again considered to be the optimal type of structure to satisfy these requirements. The most critical of these roles was the local passenger loads in the aisle section of the floor. The supporting structure had to be very stiff in bending such that passengers would feel minimal motion when walking. Sandwich panels offered a very high bending stiffness-to-weight ratio and were therefore ideal for this purpose.

The local loads on the outboard floor sandwich panels are passenger standing loads while they are in their seating area. These loads are not as severe as the loads in the central aisle (walking section) of the floor. The seat loads are not applied directly to the floor because the attachment points are on a side rail (attached to the side truss) and on the longitudinal steel channel running under the bus floor.

A plot of the proposed lightweight floor design is presented in Figure 5.6. There were two potential configurations for this design. Both were exactly the same as far as materials and fabrication process. The difference was in the number of floor panels. The first configuration had the floor fabricated in three longitudinal sections. The second configuration had the two outboard floor sections fabricated in two longitudinal pieces, with the central floor section still in one piece. The second configuration offered no structural or weight reduction advantage, and was only presented as an alternative should production deem one full-length panel too complicated to implement. Figure 5.6 shows only the first configuration.

For both configurations, the longitudinal break line for the sections was at the seat track directly above the longitudinal steel channels. All sections were sandwich panels with a thin upper skin of metal or FRP, a structural core, and a lower metal or FRP skin.

A central tunnel was located under the central floor section sandwich panel; however, similar to the current configuration, it was not structural. Having a structural central tunnel to increase the floor stiffness was initially one of the proposed designs; however, it was considered too difficult to incorporate into the current process. In the final analysis, a sandwich panel floor without a structural central tunnel satisfied the design criteria and was lighter. The current central tunnel consists of a series of tubes between the longitudinal channels that are attached to the underside of the floor. The new central tunnel configuration will most likely be sheet metal, aluminium extrusions, or pultrusion. There is not expected to be any associated weight increase with the new central tunnel.

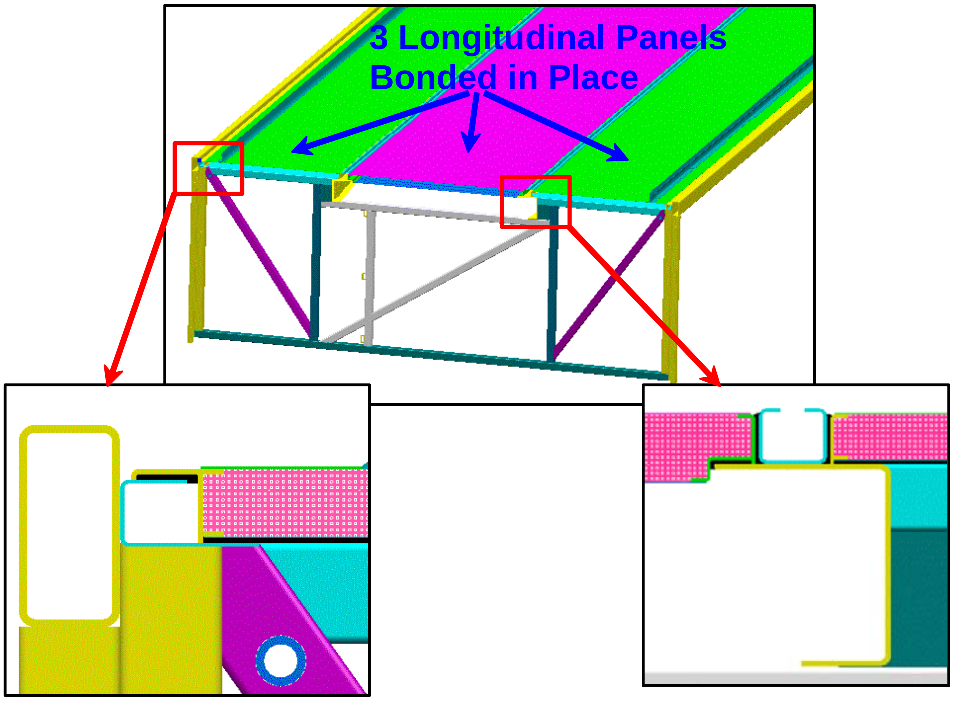


Figure 5.6: Proposed Lightweight Floor Design Concept

The advantages to the floor design in Figure 5.6 were as follows:

- Increased torsional stiffness of the vehicle;
- Easier access to service tunnel during manufacturing;
- Better thermal insulation as compared to wood; and
- Less interior finishing needed to install the flooring.

The disadvantages of this type of design were as follows:

- Handling of large components; and
- Reduction of flexibility for motor home (requires new method to make access hole).

The unknowns with this design were the stiffness of the glued joints, the selection of the proper adhesive, attachment mechanisms for motorhome parts, and the acoustic properties as compared to the current plywood floor.

5.4 STRUCTURAL ANALYSIS OF CONCEPTS

The fundamental structural criteria for the new designs were that they be lightweight and match the stiffness of the current bus structure while keeping within the design stresses. To match these criteria, a structural analysis was performed to determine the minimum required roof and floor sandwich panel dimensions. For all analyses, a perfect bond was considered between parts that were joined through adhesives. This was considered valid for this part of the project. Full consideration of the adhesive response will be carried out in the detailed design.

In addition, while several variations of the floor and roof designs were proposed, the overall basis for these designs was a sandwich panel spanning the length of the vehicle. Therefore, while multi-piece panels may ultimately be used in the design, the analysis was completed using single-piece sandwich panels for the floor and roof top. Details of the joints and connections will be completed in the detailed design stage.

Three design loads conditions were analysed. The first was a 3 *g* vertical load representative of the bus riding over a bump in the road at highway speed. This is considered the most critical of the bus design loads.

The second load case was a torsion load representing the load from a single bus tire riding up on a curb. The numerical representation of this load was the application of a vertical load at the left front side (driver's) tire location while constraining all other tire locations.

The third design load case was a rollover load condition. Even though the new structure was not being designed for rollover considerations, it was being evaluated for these purposes. Based on data from previous bus rollover tests (obtained through discussions between Prévost Car and the Cranfield Impact Testing Centre), it was estimated that the front and rear caps (with the addition of rollbars) would carry approximately 60 percent of the rollover load and the window posts would carry the remaining 40 percent. For the analysis performed in this phase of the project, it was further assumed that 40 percent was evenly distributed over the window posts.

5.4.1 *Roof Analysis*

The roof structural analysis was performed by first isolating a section of the current roof structure as shown in Figure 5.7. The structure consisted of a section of the roof, one window post, and a section of the side truss. This section was analysed under the design loads to establish the baseline stiffness and strength. The new design would then have to match this stiffness and strength.

The section of the bus, as shown in Figure 5.7, was then modified to incorporate the new lightweight sandwich panel roof structure. An iterative design process was then performed through resizing of the components (skin and core thickness) and re-analysing until the sandwich panel design matched the original design criteria.

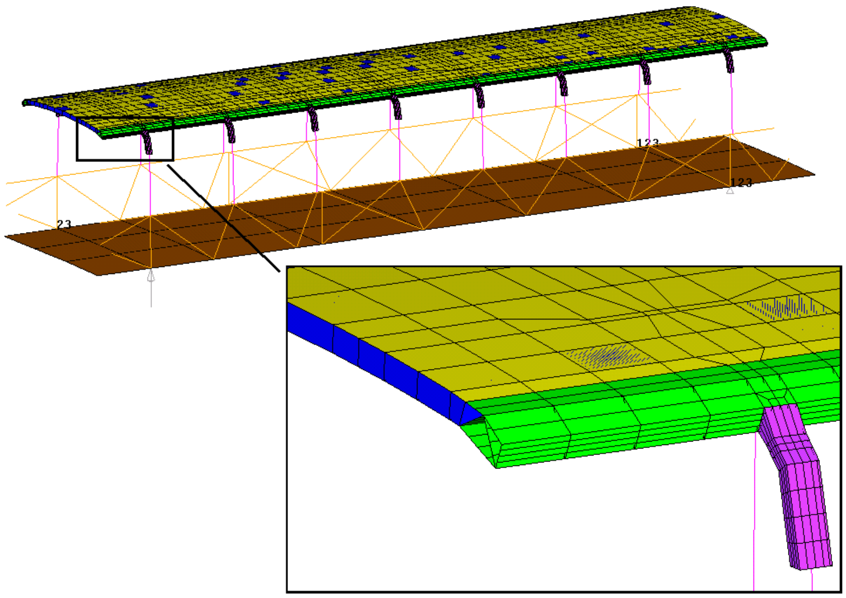


Figure 5.7: FE Model of Roof Section

Following the design of the roof section with the reduced model, the new roof design was incorporated into the full bus FE model and analysed for the design loads. The comparative results of the roof analysis are presented in Table 5.1. For the rollover load, the displacement is the lateral displacement at the top corner of the fourth window post behind the front cap. For the torsion load, the displacement is the vertical displacement at the top of the window post directly above the applied load (front left side). The displacement for the 3 *g* vertical (bending) load case is at the same location as for the rollover; however, the vertical component of displacement is presented.

Table 5.1: Comparison of Results of Analysis of Roof

Load Case	Stiffness Change
Rollover	-1%
Torsion	1%
3 *g* Vertical	17%

The results show a marginal decrease in the rollover stiffness of the bus but an increase in both torsional and bending stiffness. These results were considered acceptable for the preliminary design. A complete assembled FE model will also be created consisting of the new floor and roof concepts for verification of the roof in the complete bus structure. It is also expected that the detailed design process will produce some changes in the sandwich panels and other connecting components in the bus. At this time, more closely matching the rollover stiffness of the bus will be addressed.

5.4.2 *Floor Analysis*

The floor structural analysis was performed on a complete bus model that incorporated the new floor sandwich panel design as shown in Figure 5.8. Similar to the roof design process, the new floor design was obtained through an iterative process where the lightweight sandwich panel was developed to match the stiffness of the current floor design while staying within the strength limits. The stiffness was measured by comparison of the deflection of the overall bus structure.

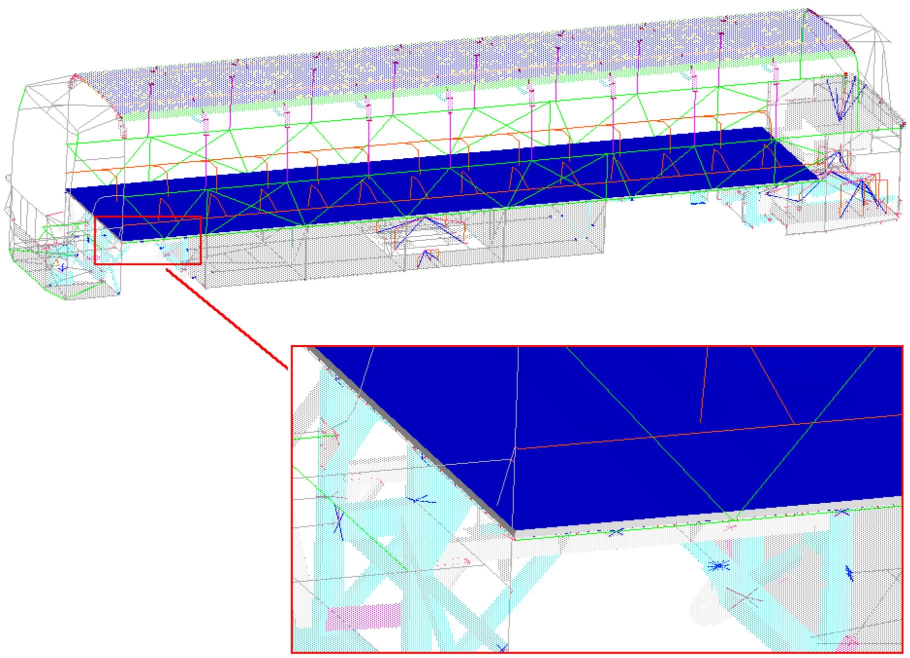


Figure 5.8: FE Model of Bus with New Floor Structure

The results of the floor analysis are presented in Table 5.2. For the torsion load, the displacement is the vertical displacement just above the applied load at the front left (driver's) side of the floor. The displacement for the bending load case is the vertical displacement at the top corner of the fourth window post behind the front cap. The displacement for the rollover load case is at the same location as for the bending; however, the lateral component of displacement is presented.

Similar to the results for the roof analysis, the new floor design showed a marginal drop in bending stiffness but an increase in both torsional and lateral stiffness. As noted in Section 5.4.1, the overall detailed design process will address this issue.

Table 5.2: Comparison of Results of Analysis of Floor

Load Case	New Floor Only Stiffness Change
Rollover	33%
Torsion	1%
3 *g* Vertical	-1%

Similar to the results for the roof analysis, the new floor design showed a marginal drop in bending stiffness but an increase in both torsional and lateral stiffness. As noted in Section 5.4.1, the overall detailed design process will address this issue.

In addition to the overall bus stiffness, the local floor stiffness (from passenger loads) of any new floor had to match the current floor. This stiffness has been established historically and, as shown in Figure 5.9, Prévost has performed testing to quantify the local floor stiffness. This curve plots the local deflection of the floor from a simulated passenger-walking load. This is the baseline stiffness that had to be matched in the design of any new lightweight floor.

The new lightweight floor must also be able to withstand impact from dropped objects. Testing was performed on various sandwich panel configurations against the current plywood floor for the local design considerations. The results of these tests are summarized in Section 6.

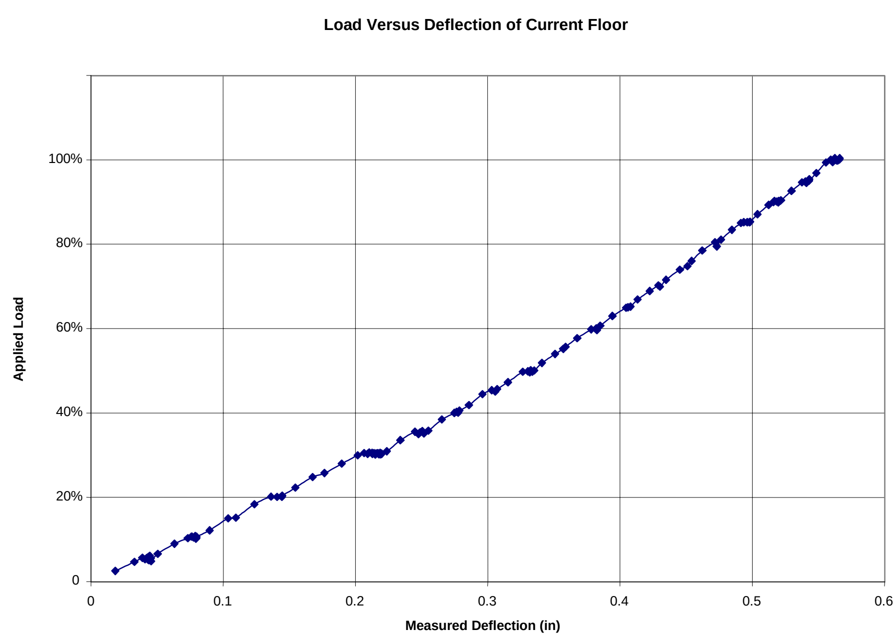


Figure 5.9: Experimentally Measured Local Stiffness of Current Bus Floor

5.5 PROCESS REQUIREMENTS

During the initial design stage, it was essential that the requirements of the production line be established and incorporated into any potential designs. Overall, the primary requirement specified by Prévost was that the new lightweight designs be readily incorporated into the current production line without increased floor space requirements. This was an essential requirement when considering the new designs.

In addition to this, the following objectives were specified by the process department as being very important for production of any new lightweight designs:

- Use Just In Time manufacturing process instead of stocking components;
- Standardize processes;
- Use less than one hour for a component assembly on-line;
- Keep customer options as long as the line does not slow down;
- Establish any new production process according to well-recognized manufacturing principles concerning the areas of quality, reliability and security;
- Utilize self-positioning parts;
- Develop processes that work in parallel instead of in series;
- Ensure equal station time on the assembly line for both motor home and coach; and
- Optimize ergonomics (people and process interact most efficiently and safely).

5.6 WEIGHT AND COST ANALYSIS OF CONCEPTS

A weight and cost comparison of the current floor and roof components to the proposed lightweight designs is shown in Tables 5.3 and 5.4, respectively. The data for the current components was gathered by the Prévost process department. The weight and cost of materials and fabrication for the new designs was gathered from suppliers and fabricators with the cost of manufacturing estimated by the Prévost process department.

The estimated fabrication costs are expected to change as the designs are finalised. Fabricators were resistant to provide "hard" numbers based on preliminary designs due to concerns about being held to that price in the eventuality of design changes. Therefore, these costs will be revisited upon completion of the final designs.

Capital cost investments for the floor and roof designs are not provided in this table. It was decided that capital costs are overhead, and as long as the payback period for any design was within a given time frame, the design was acceptable. In addition, Prévost did not want to eliminate certain designs that could provide significant weight reduction because of this initial capital cost.

All of the floor sandwich panels, except for those fabricated from a balsa or Nidacore core, have costs and weights for perimeter aluminium extrusions that "close-in" the exposed edges.

The balsa and Nidacore cores were considered to have sufficient strength and stiffness to eliminate this requirement and needed only sealant to close off exposed edges.

The results of the cost analysis show that all of the design configurations are more expensive than the current costs; however, some of these costs are not significant, particularly for the proposed floor designs. The lowest of the cost increases was 12 percent for the floor designs and 18 percent for the roof designs. Consequently, the floor concepts have a lower cost impact than the roof concepts. It is expected that these costs will decrease as the designs are finalized.

The results of the weight analysis show that all of the configurations offer very good weight reduction, with the greatest savings coming from FRP skins and a Nidacore core. On average there is a 43 percent (331 kg) decrease in weight for the floor designs and a 48 percent (290 kg) decrease in weight for the roof designs.

Even though there were only two proposed designs for the roof and one for the floor, there are many possible materials that can be used to fabricate these components. Tables 5.3 and 5.4 present the evaluation of each of these possible configurations.

Table 5.3: Weight and Cost Comparison of Current and Proposed Floor Designs

Concepts	Weight		Weight Saved		Weight Saved (%)	Cost Saved (%)
	kg	lb.	kg	lb.		
Original Floor	762	1676				
I: 3 Full Length Floor Panels with FRP skins and Klegecell foam core	379	834	383	843	50%	-17%
II: 3 Full Length Floor Panels with FRP skins and Balsa core	378	832	384	845	50%	-14%
III: 3 Full Length Floor Panels with FRP skins and Nidacore core	369	812	393	864	52%	-12%
IV: 3 Full Length Floor Panels with FRP skins and Corecell core	387	851	375	825	49%	-25%
V: 3 Full Length Floor Panels with Aluminum skins and Klegecell foam core	430	945	333	732	44%	-20%
VI: 3 Full Length Floor Panels with Aluminum skins and Balsa core	429	943	333	733	44%	-16%
VII: 3 Full Length Floor Panels with Aluminum skins and Nidacore core	420	923	342	753	45%	-15%
VIII: 3 Full Length Panels Aluminum skins and Corecell core	437	962	325	714	43%	-28%
IX: 3 Full Length Floor Panels with Al/SS skins and Klegecell foam core	486	1069	276	607	36%	-27%
X: 3 Full Length Floor Panels with Al/SS skins and Balsa core	485	1067	277	609	36%	-24%
XI: 3 Full Length Floor Panels with Al/SS skins and Nidacore core	476	1048	286	629	38%	-22%
XII: 3 Full Length Floor Panels with Al/SS skins and Corecell core	494	1087	268	590	35%	-35%

Table 5.4: Weight and Cost Comparison of Current and Proposed Roof Designs

Concepts	Weight		Weight Saved		Weight Saved (%)	Cost of Concept ($CAN)	Cost Saved ($CAN)	Cost Saved (%)
	kg	lb.	kg	lb.				
Original Roof	599	1317				6883		
I: Monocoque Infused One Piece Roof With Integrated Window Posts with FRP skins and Klegecell foam core	273	600	326	718	54%	8276	-1393	-20%
II: Monocoque Infused One Piece Roof With Integrated Window Posts with FRP skins and Balsa core	283	622	316	695	53%	8258	-1375	-20%
III: Monocoque Infused One Piece Roof With Integrated Window Posts with FRP skins and Nidacore core	297	654	302	664	50%	8094	-1211	-18%
IV: Monocoque Infused Four Piece Roof With Integrated Window Posts with FRP skins and Klegecell foam core	279	614	320	703	53%	9099	-2216	-32%
V: Monocoque Infused Four Piece Roof With Integrated Window Posts with FRP skins and Balsa core	289	636	310	681	52%	9081	-2198	-32%
VI: One Piece Roof Top, Bonded Window Post Modules to Aluminum Extrusions, using FRP skins and Klegecell foam core	318	699	281	618	47%	9139	-2256	-33%
VII: One Piece Roof Top, Bonded Window Post Modules to Aluminum Extrusions, using FRP skins and Balsa core	342	753	257	565	43%	9764	-2881	-42%
VIII: One Piece Roof Top, Bonded Window Post Modules to Aluminum Extrusions, using Al skins and Klegecell foam core	341	751	258	567	43%	9376	-2493	-36%
IX: One Piece Roof Top, Bonded Window Post Modules to Aluminum Extrusions, using AL skins and Balsa core	366	804	233	513	39%	9251	-2367	-34%

5.7 COMPARISON OF CONCEPTS

An overall comparison of the proposed lightweight floor and roof designs is presented in Figures 5.10 and 5.11, respectively. These plots show the difference in cost and weight separately. The concept numbers correspond to the written descriptions as indicated in Tables 5.3 and 5.4.

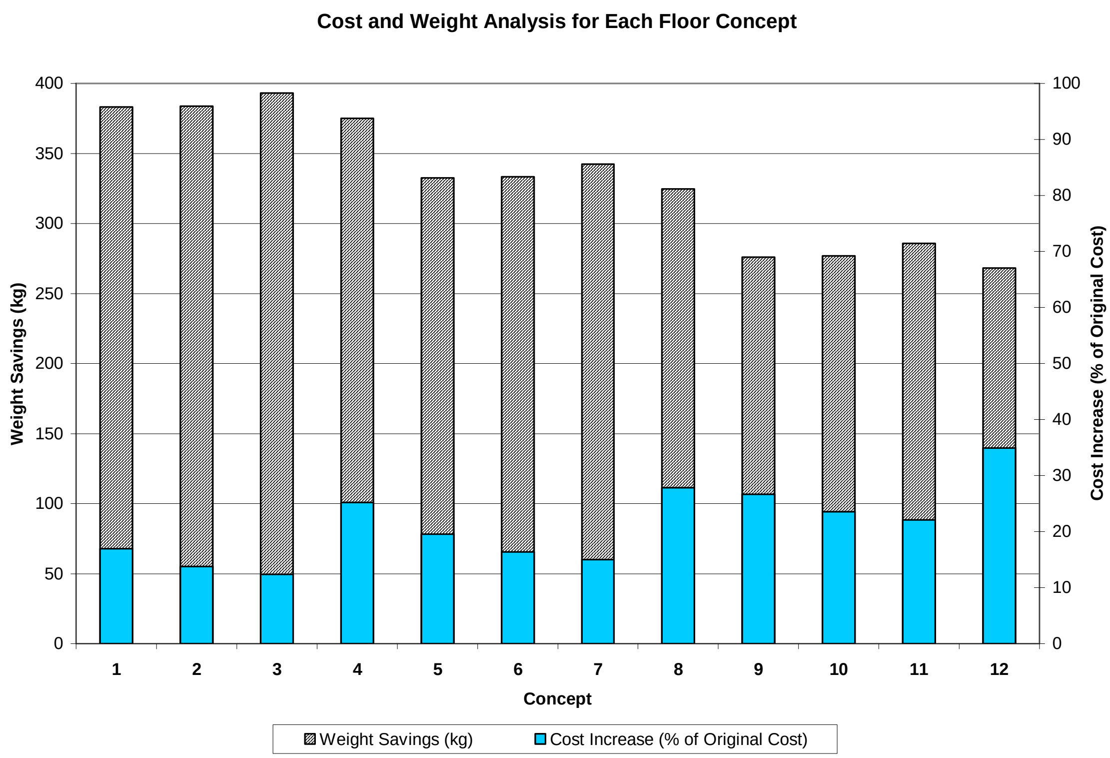


Figure 5.10: Overall Comparison of Proposed Lightweight Floor Designs

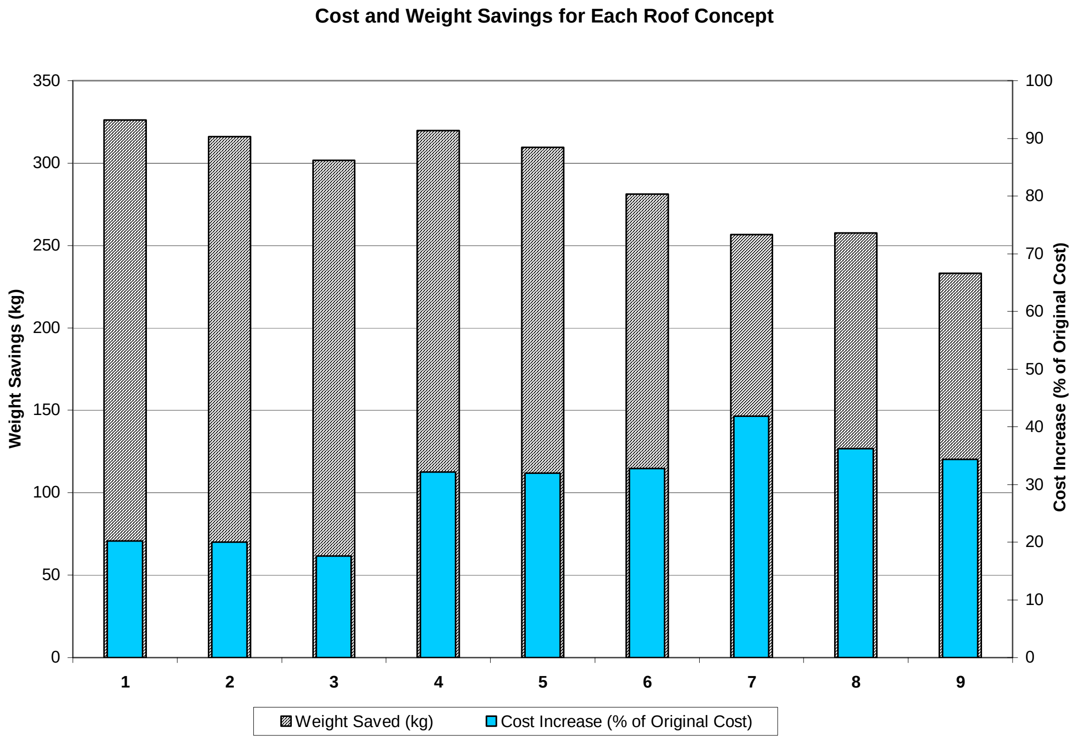


Figure 5.11: Overall Comparison of Proposed Lightweight Roof Designs

From the above plots, it is shown that most of the configurations offer substantial weight savings with varying degrees of expenditure. For the floor designs, the configurations with FRP skins offered the lowest cost increase. For the roof designs, the one-piece monocoque design offered the lowest cost increase.

5.8 RECOMMENDED DESIGNS

The estimated weight and cost of the lightweight designs show that there were several candidate configurations that could fulfil the requirements of the floor and roof while also reducing weight over the current designs. However, all proposed concepts resulted in an overall increase in the cost of the components. These costs will hopefully be reduced throughout the detailed design process, as the component designs are optimized and finalized.

These values were the most accurate available based on the gathered data. However, it was expected that the numbers would be refined as the detailed design progressed into the fabrication stage. The cost analysis will be revisited upon completion of the detailed design to more accurately determine the material and process costs.

It was anticipated that some of the design configurations would be eliminated based on more refined design criteria. These decisions were based on the results of internal Prévost meetings involving the engineering and process departments as the design progressed.

This was an iterative consultation process set-up between these departments where new issues were continually being raised that affect the design requirements.

Prévost was relying on information from ALCAN/Alusuisse regarding the viability and cost to manufacture the aluminium-fastened concept. The results of the study so far show a weight savings of 559 kg with a cost increase 13 percent for the new aluminium components. Work is continuing to develop a more detailed design using this manufacturing technique.

6. DETAILED DESIGN OF HYBRID ROOF AND FLOOR COMPONENTS

While both the hybrid and all-aluminium designs were still being considered by Prévost for the design of a lightweight bus, at this stage of the project the complete assessment of the all-aluminium concept was not complete. A design assessment was being performed by ALCAN as detailed in Section 5.3.1.1; however, this assessment was not completed before the end of the project. Consequently, the detailed design was initiated on the hybrid designs.

The detailed design of the lightweight hybrid roof and floor components was started even though final configurations had not been chosen for the floor and roof. It was known that the hybrid design would partially consist of sandwich panels for the floor and roof. However, the core and skin materials to be utilized were not known since these choices depended on the material performance to a set of criteria that Prévost Car was developing during the design procedure. Whether one or several panels would be used or whether extrusions would be used was not known. However, the one common fundamental feature of the roof and floor hybrid designs was the sandwich panel. Consequently, the detailed design was started while the final particulars of each design were determined. It was further felt that the final configuration would be achieved through the detailed design process.

6.1 FLOOR DETAILED DESIGN

The detailed design of the floor required designing for the global requirements such as overall bending and torsional stiffness, and strength. The local detailed design requirements were the local stiffness requirements for passenger walking areas, dropped object damage control, adhesive details, floor panel perimeter details, seat track details, and attachment of the floor to the bus structure. The detailed design process is outlined in Sections 6.1.1 and 6.1.2.

6.1.1 Global Design of Floor

The requirements of the global design of the floor were mostly satisfied during the earlier task of concept structural analysis as presented in Section 5.4.2. This analysis was required earlier to determine the weight and cost of designs that would meet the global stiffness and strength requirements of the bus.

For the floor, the requirements were that the overall bending and torsional stiffness of any lightweight design had to match the stiffness of the current bus structure. As shown in Table 5.2, the deflection corresponding to the lateral and torsional stiffness of the new hybrid floor design compares very well with the current bus deflections, with only a slight drop in bending stiffness. Following the detailed design process, the overall stiffness will be rechecked and modified (if necessary) to ensure it matches the stiffness of this current floor.

6.1.2 *Local Design of Floor*

The requirements for the local design of the new floor components were much more involved and critical than the global design. The local design requirements ultimately determined the final configuration of the floor. These design requirements are presented in Sections 6.1.2.1 to 6.1.2.3.

6.1.2.1 *Drop Test*

An experimental test was designed and performed by Prévost to accurately define an acceptable degree of damage to the bus floor from dropped objects. This was based on the fact that the current plywood floor offered very good resistance to dropped objects, resulting in little or no damage.

The test set-up was designed and fabricated for this purpose. The maximum energy and permanent deformation from impact were first determined by performing the drop test on the current bus floor. When the maximum acceptable damage was achieved, this energy level was then used to test all possible candidate floor materials and configurations. The drop test instrument is shown in Figure 6.1.

Figure 6.1: Drop Test Instrument

From the drop test results, the optimal materials for the skin and core were chosen. The optimal configuration was one that met the requirement of minimal permanent deformation with comparative performance to the current bus floor. Results of the test, as shown in Figure 6.2, show that the new floor designs are capable of offering a better level of performance to impact loads than does the current plywood. Prévost product experts are satisfied that the two leading core panels meet the impact resistance requirements of a bus floor.

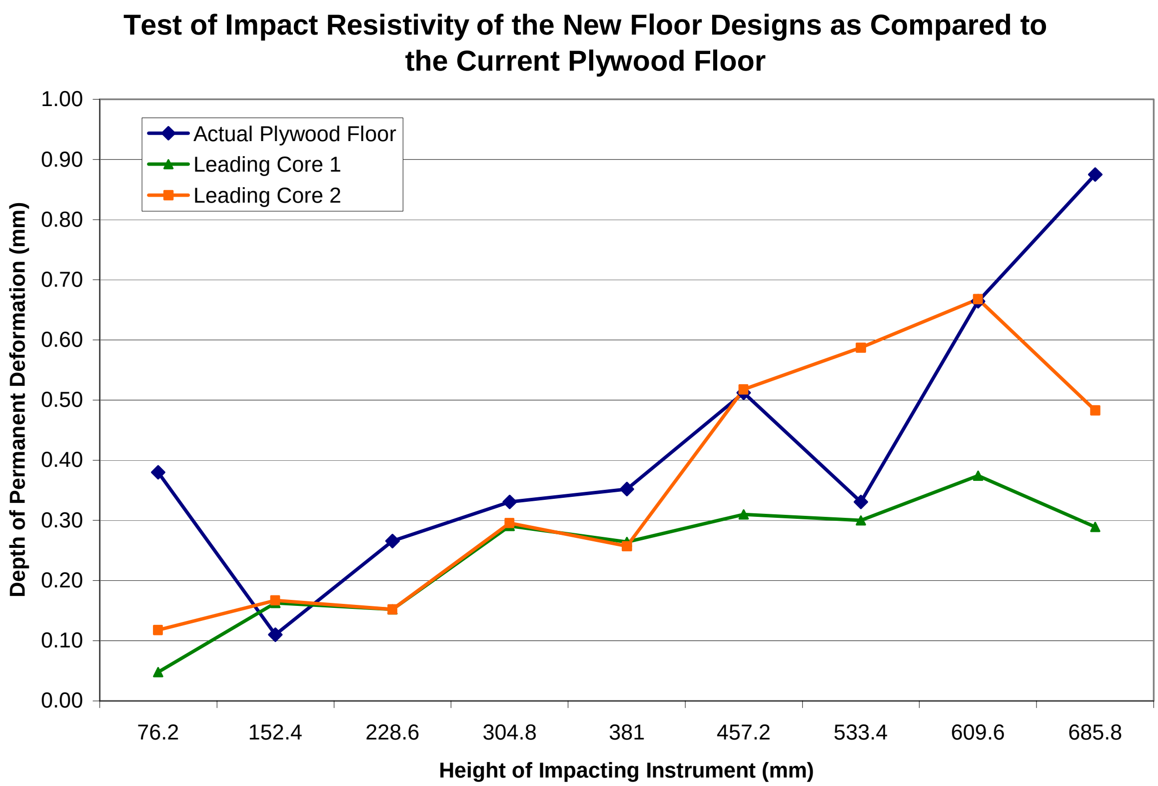


Figure 6.2: Results of Drop Test for the Leading Floor Designs Compared to the Current Floor

6.1.2.2 Concentrated Static Load Test

It was known that the current plywood floor met the requirements for acceptable damage due to a concentrated load. Again, this damage was never quantified. An experimental test was designed by Prévost to accurately define an acceptable degree of damage to the bus floor from concentrated loads.

The test set-up was designed and fabricated for this purpose. A minimum floor test area was chosen by Prévost in-house experts as well as various design loads for the test. The test was first performed on the current bus floor. Permanent deformation was measured for each test load. The test was performed on the various new floor sandwich panel samples as well. The testing apparatus is shown in Figure 6.3.

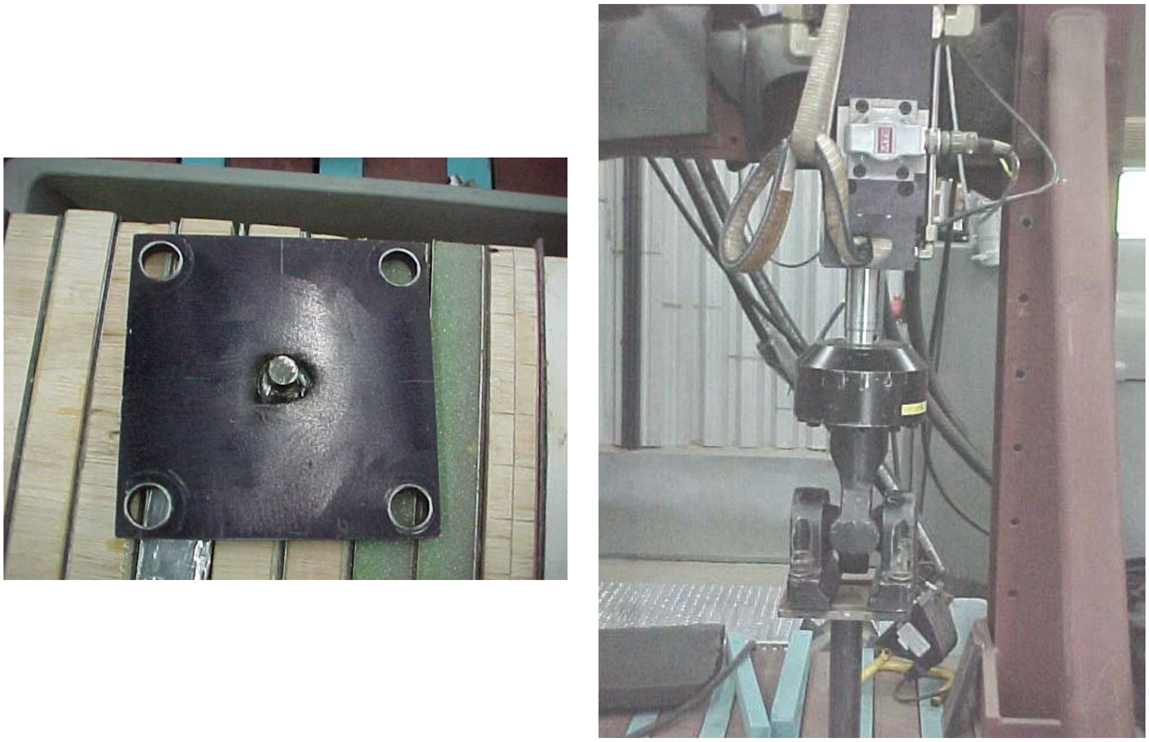


Figure 6.3: Testing Apparatus Developed for the Concentrated Load Test

From the results of the test, it was possible to see which potential floor sandwich panels met the minimum requirements identified by Prévost for the test. Several candidate materials performed well in the test.

6.1.2.3 Stiffness Testing of Floor Panels

One of the most critical aspects of the design of a new floor is to ensure that passengers do not feel excessive motion/deflection when walking. It was known that the current plywood floor (and support structure) met the requirements for stiffness due to passenger walking loads; however, this stiffness was never quantified. Therefore, experimental tests and numerical analyses were performed by Prévost to accurately define an acceptable stiffness of the floor to withstand the passenger walking loads.

In an effort to expedite the testing and selection process, FEA was employed to determine a starting point for the testing. The minimum unsupported span was modelled and subjected to the passenger loads. The FE model is shown in Figure 6.4. An iterative approach was used to determine skin and core dimensions to meet the stiffness requirements of the passenger floor. The test set-up used to determine the current stiffness of the floor, as described in Section 5.4.2, was used to verify the FE results.

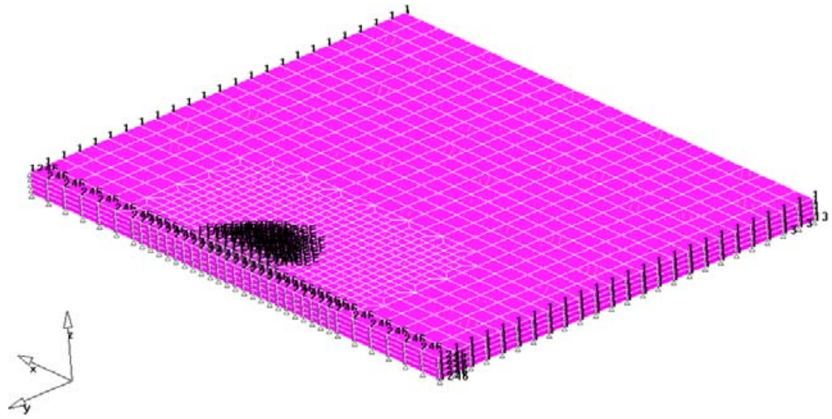


Figure 6.4: FE Model Used to Determine the Stiffness of the New Floor Design Concepts

For the physical test, the test method and minimum criteria set were developed through consultation with Prévost in-house product experts; the objective being to determine the minimum acceptable stiffness level for the passenger floor. This was largely based on the qualitative opinion of the product experts as the test progressed. A floor panel undergoing the stiffness test is shown in Figure 6.5.

Figure 6.5: New Floor Design Sample Being Tested for Stiffness Properties

Several different test panels were fabricated with varying materials and geometry and tested by Prévost personnel for the "feel" as compared to the current floor. As a result of the stiffness tests, the required thickness of the skins and core combination was identified that met the local stiffness requirements for the passenger floor.

6.2 ROOF DETAILED DESIGN

The roof detailed design required designing components for global requirements such as torsional and bending stiffness, incorporation of window posts, investigation for rollover protection and thermal insulation. The local design requirements were impact resistance to dropped objects (roof top), incorporation of parcel rack attachment points, attachment to the side truss, and stiffness of the window posts.

6.2.1 *Global Design*

Similar to the global design of the floor, the global design requirements for the roof were mostly satisfied during the earlier task of concept structural analysis as presented in Section 5.4.1. This analysis was required earlier to determine the weight and cost of designs that would meet the global stiffness and strength requirements of the bus.

For the roof, the structural requirements were that the overall bending and torsional stiffness of any design had to match the stiffness of the current bus structure, the roof had to be capable of carrying the parcel rack loads, and the roof had to be investigated for the potential of rollover protection. In addition, one very important non-structural consideration for the roof is thermal insulation. In hot climates, such as the southern United States, roof temperatures can get very high. Conversely, in cold climates such as northern Canada, the roof temperatures could be very low. Therefore, the roof materials had to be capable of supplying an insulation R-value comparable to the existing bus roof materials. True to the nature of the project of utilizing the best material for the application, the new roof serves two purposes. The core material acts as the thermal insulation, eliminating the need for the insulation that is currently used in the roof.

6.2.1.1 Rollover Design

An area of concern was safety of the motorcoach. Currently there are no Canadian or North American regulations concerning rollover requirements of intercity coaches. In Europe a standard has been introduced that all coaches must meet. The Economic Commission for Europe (ECE) tourist coach regulation, R66, identifies a certifying procedure and a set of minimum requirements that the coach must meet for a rollover. Although this standard does not apply to the North American market, it was used when looking at rollover load conditions. It is expected that some future North American standard (if implemented) would be at least partially based upon the ECE R66.

Compliance with the R66 standard is verified through full-scale physical testing or a combination of numerical modelling and individual component testing. However, the purpose of this study was not to evaluate the bus structure against R66. For design purposes, Prévost required to know the energy absorbed by the roof structure (more specifically the window post) in order to design the new roof for rollover considerations.

In conjunction with this, Martec Limited performed a rollover simulation (FE analysis) using the explicit FE program, LS-DYNA. A section of the bus was modelled to include the new roof and window posts and a rollover analysis was performed to simulate the requirements of

the R66 standard. A plot of the secti
impact is shown in Figure 6.6.

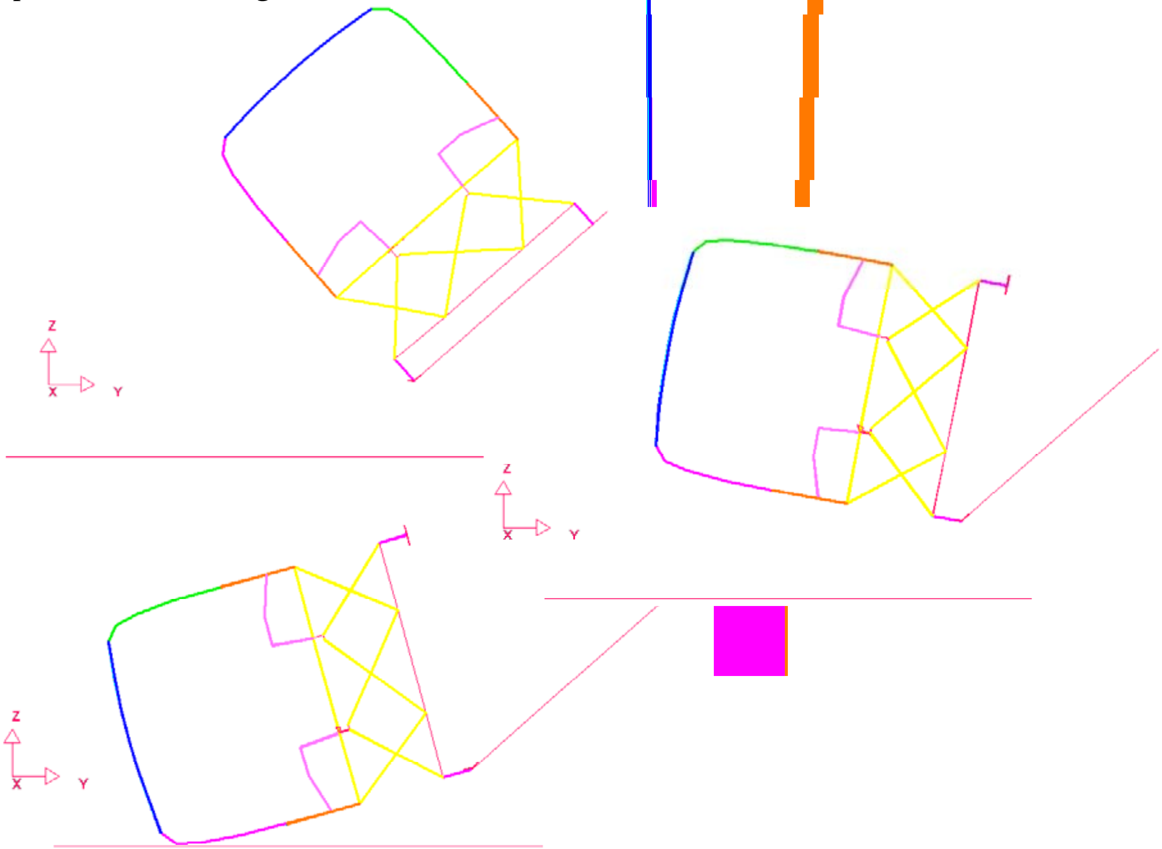


Figure 6.6: FE Model and Displaced Shape Results of Rollover Analysis

From the simulation in the Figure 6.6, it can be seen that the vehicle impacts at the curved section of the window post. From the LS-DYNA output, the total internal energy absorbed by this post during the impact was approximately 9910 Joules as read from the graph in Figure 6.7.

From the R66 energy calculation formula, the total energy of the impact for the XLII coach is calculated as follows:

$$E = 0.75 \cdot M \cdot g\left(\sqrt{\left(\frac{W}{2}\right)^2 + Hs^2} - \frac{W}{2 \cdot H}\sqrt{H^2 - 0.8^2} + 0.8 \cdot \frac{Hs}{H}\right)$$

where: E = Total Energy of Rollover
M = Unladen Kerb Mass of the Vehicle = 16,330 kg
G = Gravity = 9.8 m/s^2
W = Overall Width of the Vehicle = 2.6 m
Hs = Height of the Centre of Gravity of the Unladen Vehicle = 1.4 m
H = Height of the Vehicle = 3.56 m

yielding an energy associated with rollover of 115,038 Joules.

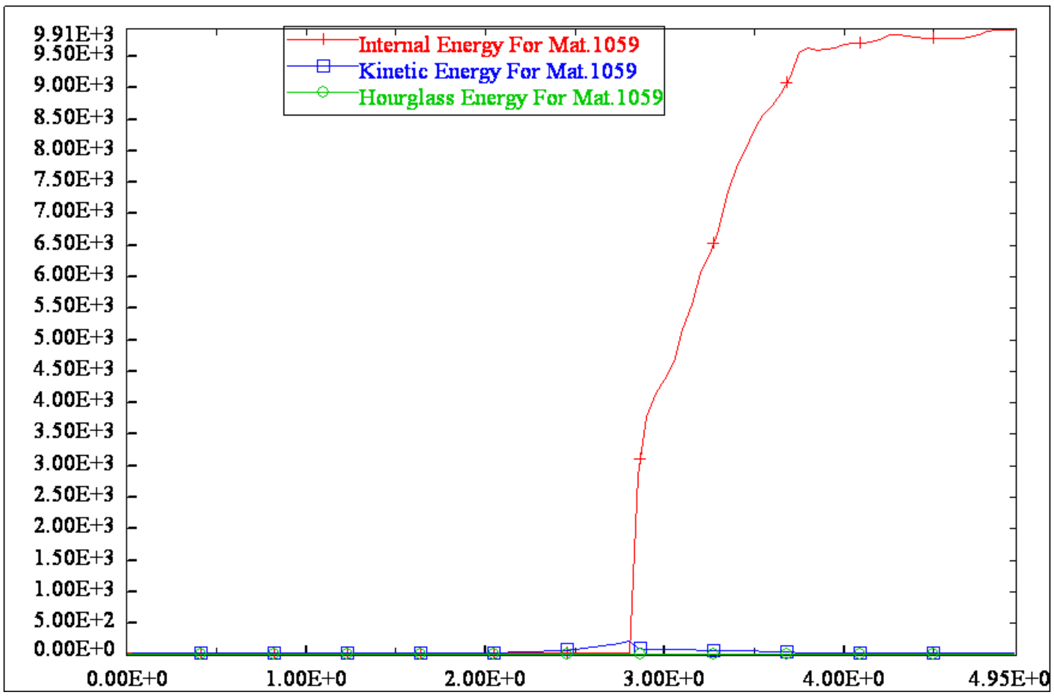


Figure 6.7: Energy Absorbed by One Window Post Based on R66 Rollover Analysis Performed Using LS-DYNA

The calculated R66 energy is distributed along the entire length of the vehicle, whereas the LS-DYNA energy is only for the modelled section of the bus. This section is 9.7 percent of the total bus length and weight. Therefore, the corresponding energy for the full bus, as predicted by LS-DYNA, would be roughly (9,910/0.097) 102,165 Joules. This energy value shows good agreement for the R66 calculations prediction of 115,038 Joules.

Although the new lightweight bus roof is not being specifically designed for rollover, Prévost Car recognizes the future importance of this for bus safety and is therefore evaluating the new designs for this potential.

A series of tests was performed at the Prévost test facility, where a mass was dropped on a window post with the energy equivalent to that taken by one window post during a rollover as per the ECE R66 standard.

6.2.2 Local Design

6.2.2.1 Attachment of the Side Truss

The attachment of the window posts to the side truss was a very important consideration in the design. It is mainly through this joint that the roof is supported and offers resistance to rollover as described in Section 6.2.1.1. With the new designs developed under this project, adhesives play a large role in creating this connection. Because the failure mechanism (shear, peel) was not known at the connection and because adhesives have different failure strengths depending on the failure mechanism, physical testing was required.

The objective of this test was to determine the strength of different adhesives for attachment of the window post to the side truss. Specimen posts were bonded to a mock up of the side truss and subjected to an impact load as determined from the rollover analysis and ECE R66 calculations of Section 6.2.1.1. Figure 6.8 shows the drop test being performed. The current welded steel post to the truss was tested to provide a baseline in which to compare the other specimens. The test set-up was such that not only the permanent deflection, but also the maximum deflection could be measured. From the results of the test, Prévost was able to choose an adhesive that satisfactorily met the needs of this joint.

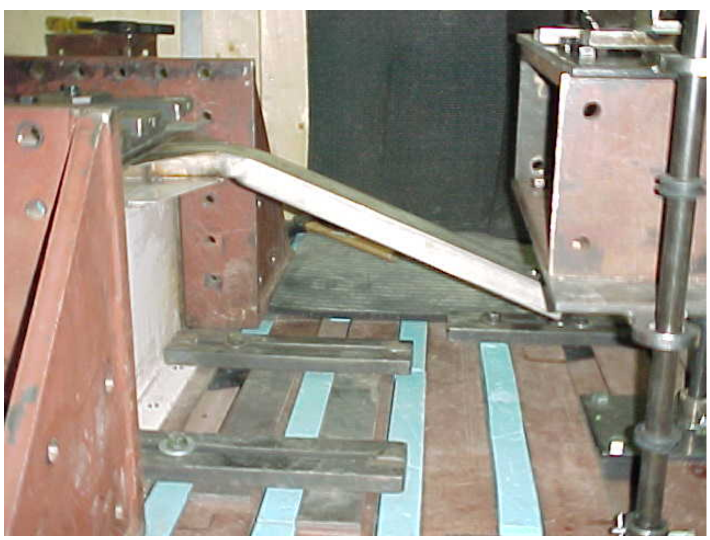


Figure 6.8: Window Post Undergoing the Drop Test

6.2.2.2 Window Post Stiffness

In order to reduce weight, the roof design developed in this project utilizes FRP and Aluminium to a much further extent than the current structure. One area of the roof where weight savings were investigated was the window posts. Finite element studies as well as physical testing was performed to determine the dimensions of a new post made from a new lightweight material other than steel.

As shown in Figure 6.9, an FE model was updated from the current steel posts to aluminium and FRP. The rollover load cases described in Section 5.4 were used to determine the dimensions of the posts (utilizing the new materials) that would match the performance of the current posts. Matching the stiffness of the current posts is very important to maintain the natural frequencies of the vehicle, most notably the lateral excitation frequency of the roof. This numerical analysis was performed to identify a starting position for the physical testing of the new posts.

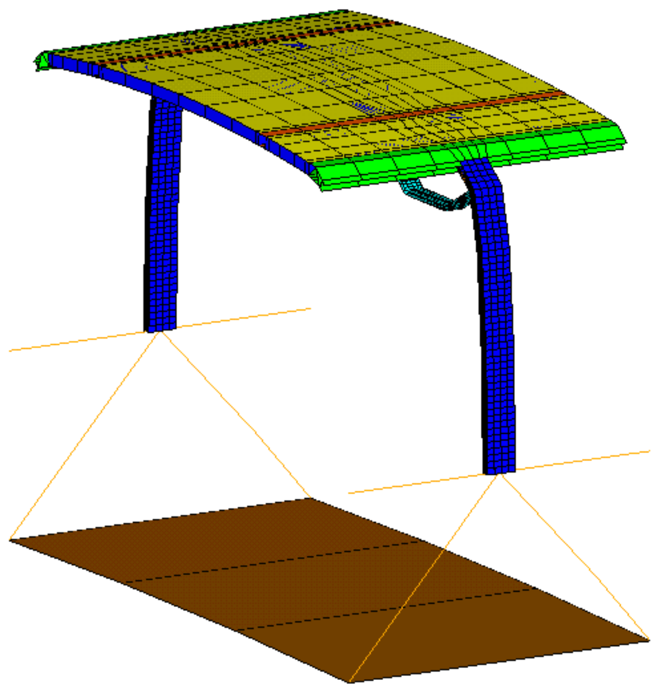


Figure 6.9: FE Model Used to Determine the Stiffness of New Window Post Designs

FE analysis alone was not enough to determine the requirements for the window posts. The post itself was not the only change to the design. The attachment of the post changed as well. Consequently, physical testing was used to determine the best design for the window post/attachment system, thus yielding posts of optimal performance. The test was performed not only to determine the stiffness of the posts, but also the stiffness of the post as attached to the side truss.

Initially testing did not yield favourable results for the new window posts. A number of posts were tested, all of which failed well below the load level of the current steel posts. Upon examination of the posts and test results, it was felt that ultimately failure of the posts did not occur, but they failed locally due a deficient design and manufacturing flaws and defects. Examples of these failures were delamination of the FRP in local area of the connection to the truss, delamination between the carbon fibre and fibreglass, failure of the post in compression, and failure of the adhesive to bond to the post. Examples of these failures of the samples posts are shown in Figure 6.10.

After meetings with the supplier to discuss these problems, it was determined that the manufacturing techniques used in the construction of the posts did not meet the requirements for a production part. The problems were corrected and post quality increased through each iteration on the manufacturing technique and improvement of the design, thereby yielding more favourable test results.

Figure 6.10: Examples of Post Failure

However, none of the hybrid composite posts were able to match the stiffness of the current steel post upon completion of testing. The main failure mode was delamination of the carbon fibre and fibreglass layers. This was not simple failure mode and more study is required to address it. Meetings have taken place with the supplier of carbon fibre, the producer of the prototype posts, and Prévost to deal with the delamination issues between the carbon fibre and fibreglass experienced in the tests.

It was, however agreed that work should not stop on the development of a composite post. Prévost is confident that with further practice, improvements to the manufacturing process, and proper selection of resin and fibres, a satisfactory post can be produced.

In order to confirm that a composite post could in fact be produced that matched the stiffness of the current steel posts, a post made entirely of carbon fibre was produced and tested. As can be seen in Figure 6.11, the experiment was a success. Although the fibreglass post is not as stiff as the current steel post, the carbon fibre post is stiffer. Conversely, fibreglass, although not as stiff as carbon fibre, can absorb more energy. It is still expected that the final composite post will be composed of both fibreglass and carbon fibre as initially proposed.

Carbon fibre is becoming more and more common in industrial applications; this is in part due to decreases in its cost. It is expected that carbon fibre prices could drop even further to one dollar US per pound for medium volume applications. Should carbon fibre be employed in larger scale applications such as mainstream automotive, suppliers have indicated the price would be in the order of fifty cents US per pound for the raw material.

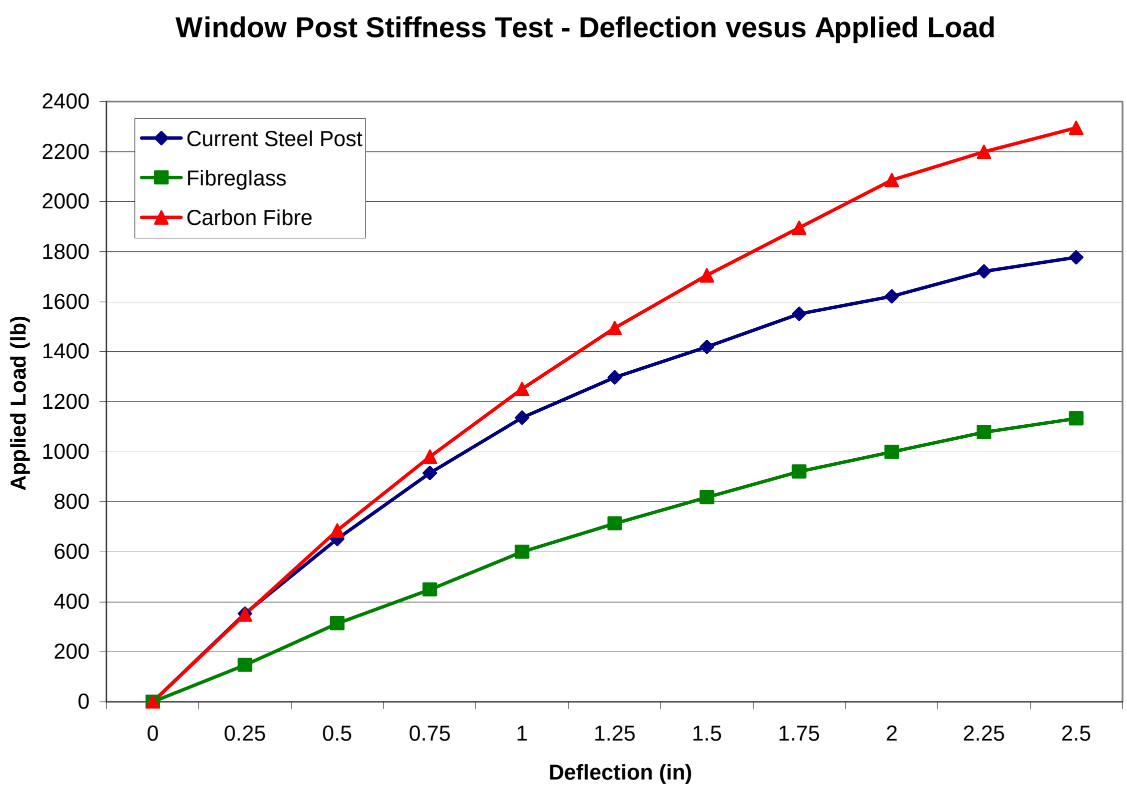


Figure 6.11: Window Post Stiffness Test Results

It is also possible to increase the stiffness of composite parts through optimal ply-orientation of the fibres in the skins. A detailed ply orientation study is quite expensive and outside the scope of this project. This type of study could be completed in the last phase of the advanced engineering project or in another project in the future.

6.3 ADHESIVES

In the hybrid design where the design philosophy is to select the best material for the application, different materials are often joined together. In this case, welding cannot be utilized. Either mechanical fastening or bonding using structural adhesives must be used.

Adhesives provide several design advantages compared to mechanical fastening, specifically for products used by the public where visible fasteners are not as aesthetically pleasing as smooth bonded panels. Adhesives are also used worldwide in heavy transportation industries.

In the past Prévost has experienced several problems when using adhesives on the production floor. Initially there was a steep learning curve before successful processes were developed to deal with the problems experienced when using adhesives. Currently, Prévost has dedicated personnel assigned to the task of developing new methodologies and tests before any new adhesive is approved. Considerable study has been given to developing an internal certification process to ensure adhesives will perform as expected. Internal tests have been developed in addition to utilizing ASTM standards for the validation process. Endurance of the glued joint especially in highly corrosive environments is of utmost importance at Prévost. To this end, an in-house salt spray test has been developed to represent in-use time cycles. Tensile testing is then performed to determine the degradation, if any, of the joint. The testing apparatus is shown in Figure 6.12.

Figure 6.12: Salt Spray Testing Apparatus and Tensile Test

With a requirement to utilize adhesives for the new lightweight hybrid designs, Prévost has investigated structural adhesives to determine the optimal type and application of adhesive. As detailed in other sections of this report, test sandwich panels were fabricated for the floor and roof structure using aluminium and FRP skins and foam core. These panels have been tested for stiffness, strength, and impact resistance and have performed well. Given that adhesives will be an integral part of the new designs, the considerations that were being investigated to provide a robust design with ways to facilitate manufacturing were as follows:

- Looking at the use of mechanical fastener in conjunction with adhesives to be able to move vehicles more rapidly along the line;
- Looking to use adhesives with reduced surface preparation requirements; and
- Having direct input from the process department on the design group.

Prévost examined a wide spectrum of adhesives during the course of this project in order to identify the best adhesive for the application that was in line with the philosophy of the project. Adhesives studied ranged from flexible polyurethanes to stiffer epoxies, Methacrylate, and Pliogrip. Considerations such as surface preparation, cycle time, and application techniques were investigated. A film type epoxy was a very promising adhesive for the fabrication of the sandwich panels. This form of adhesive allows for easy application in a mould and offers strict control over adhesive thickness, thereby minimizing material usage and weight.

Potentially, the most crucial joint for which adhesives are proposed in this project was the connection of the window post to the side truss. Initially it was proposed that a flexible urethane adhesive be used for this application. Flexible urethane is a very popular adhesive used in the bus industry. Some of its many applications are to bond the side windows, front windshield, and other semi and fully structural components. Even though recommended by industry experts, Prévost had doubts as to the effectiveness of this type of adhesive for an application such as the window posts. Test were developed to measure the stiffness and strength of this joint formed by various bonding techniques, including flexible urethane adhesives, more rigid adhesives such as epoxies and methacrylate, and the welded construction currently used (baseline). As can be seen in Figure 6.13, the stiffer adhesive could in fact form a joint as stiff as the welded one; however, the flexible urethane could not. Consequently, a rigid adhesive was selected as the preferred adhesive for this joint.

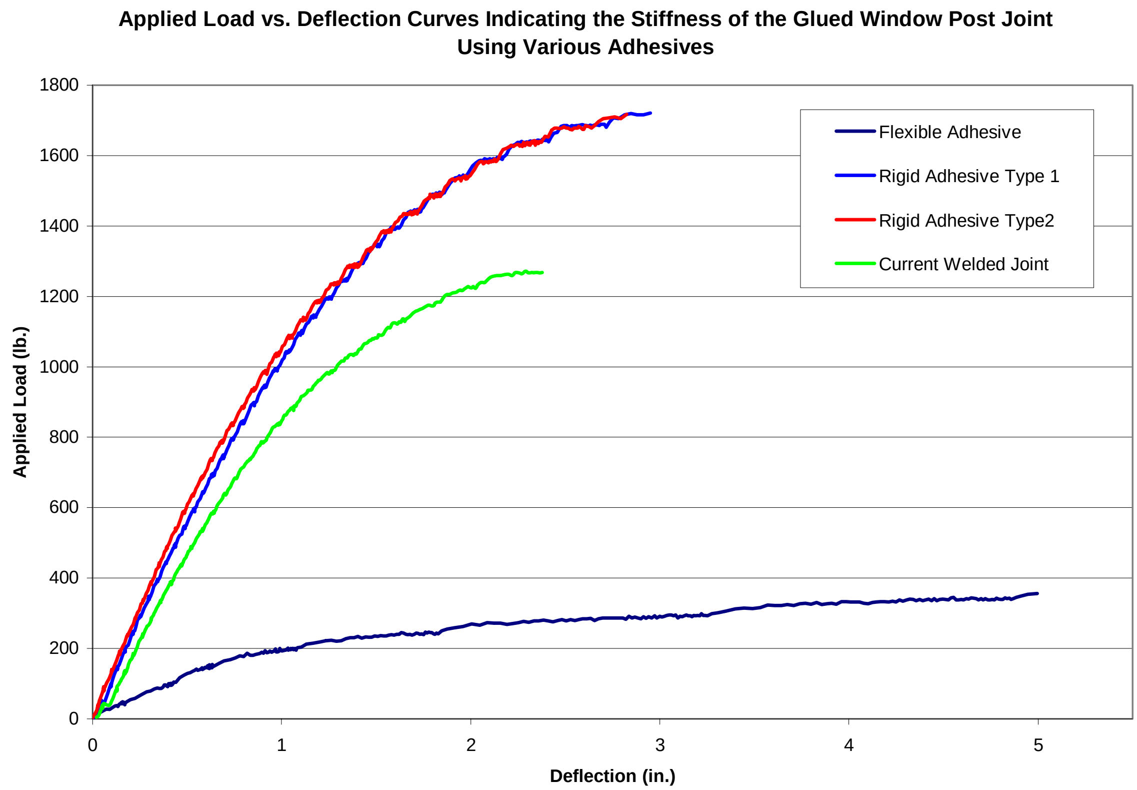


Figure 6.13: Stiffness Testing of the Window Post Connection Utilizing Various Bonding Techniques

These considerations will be kept at the forefront of any decisions made to the designs regarding the use of adhesives.

6.4 OTHER GLOBAL DESIGN CONSIDERATIONS

6.4.1 *Seatbelts*

Similar to the rollover investigation, Prévost Car also studied the new designs for future incorporation of seat belts. This investigation focused on the new floor component, more specifically the seat track, where any seatbelt loads would ultimately have to be carried.

Based on this, a study was initiated to investigate what the actual seatbelt load would be. The load is generated from the initial deceleration of the bus that results in a subsequent passenger deceleration produced by the seatbelt restraint. However, there did not seem to be a consistent deceleration value used by industry for crash data. The values found ranged from 25 *g* for passenger cars to 6 *g* for heavy vehicles. Failure of seats and seat anchorages has been observed in many collisions and indicates the need for further dynamic strength testing. There is evidence that the ECE 10 *g* requirement is a more realistic value than the 20 *g* Australian value, which is quite high for a vehicle the size of a bus.

Given the lack of regulation in North America and disagreement between bus standards utilized around the world, Prévost decided to modify its current track design. The track has been utilized for many years in Prévost vehicles and has a well-established service life. During the design phase it was decided to attach the seat track directly to the structure rather than to the floor as is currently done.

The seat track, as shown in Figure 6.14, is located at the junction of the middle and side panels of the floor, thus the floor construction has little influence on the seat belt anchorage design. The only concern with the current track was that it might not have enough lateral strength to safely carry the deceleration forces generated from a sudden stop and that the upper flanges of the track would spring open, releasing the seat hold-down bracket. If this is the case, the seat track will be modified when deceleration standards have been established for the North American bus industry.

Figure 6.14: Seat Track/Floor Configuration

6.5 LOCAL DESIGN CONSIDERATIONS

Since the new designs were modular, the details of the connection of the modules to each other and to the other structure were very important.

For the floor module, the areas where the design of connections was critical were as follows:

- seat track;
- side truss;
- air ducts;
- baggage compartment; and
- front and rear sub-frames.

For the roof module, the areas where the design of connections was critical were as follows:

- front cap;
- rear cap;
- side truss; and
- parcel racks.

Prévost designers familiar with the current design and how the new components would connect with the current structure were asked to provide the details of all connections.

6.6 DESIGN MANUAL

A design manual was prepared that provides details of all aspects of the design of the lightweight floor and roof components. This document was intended to chronicle the steps in the design process such that future advanced engineering projects within Prévost will be able to reference this information.

This document contains confidential information regarding the design of the new Prévost lightweight bus and is considered proprietary. Consequently, this document is not available as part of this report.

7. PROTOTYPE DEVELOPMENT

7.1 FLOOR PROTOTYPE DEVELOPMENT

As a result the process outlined in Section 6, a final design of the floor was completed. In addition to the new floor sandwich panel design, modifications were required to the bus model as part of the re-design for the floor. The modifications included floor member removal and other members were modified to accept the new floor panels as shown in Figure 7.1. The final skin material for the floor panels was also selected. While only one skin configuration was chosen, two leading candidates for the core material passed all the necessary criteria. The final selection of the floor core would be selected in the vehicle prototyping stage of the process.

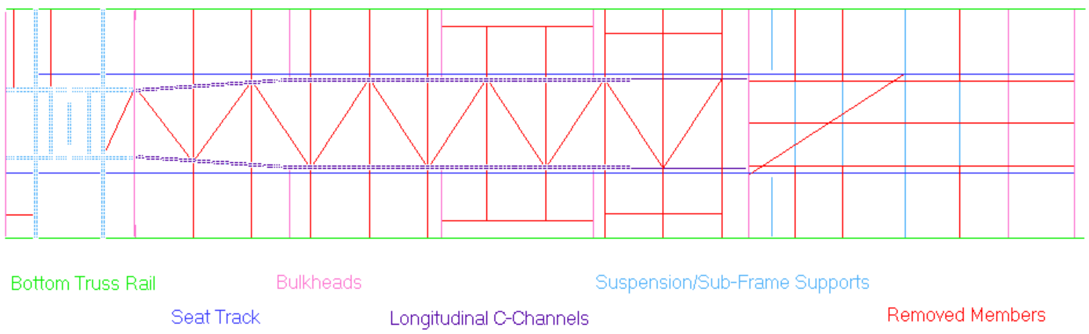


Figure 7.1: Floor Member Modifications

During this stage, Prévost's prototyping and development shop fabricated mock ups representing the overall bus structure. These mock ups were a representative cross section of the bus, 10 ft. in length. The two leading candidates (Floor 1 and Floor 2) for the floor design were installed, one in each mock up, for final evaluation. The mock ups were fully fitted on one side with the complete interior of a coach. One of the mock ups with the new floor panels installed is shown in Figure 7.2.

Figure 7.2: New Floor Sample Fitted to XLII Structural Mock Up

As well as serving as a test bed, the mock ups were used by the process and manufacturing department to estimate the time requirements and line changes necessary for the incorporation of the new floors into the production vehicles. In addition to this, they also gave production staff experience with the new structural adhesives proposed in this project. Issues such as surface preparation, application technique, working time, and odour could all be addressed. The installation of the new floor proved very simple and easy. The process department expects significant time reductions on the assembly line utilizing this new floor concept. With a better understanding of the requirements to install the new floor, the process department is now re-evaluating its original installation time as presented in Section 5.6.

With the new floors installed (Floor 1 and Floor 2), Prévost staff were able to get a feel for the stiffness of the installed floor panels. It was expected that the previously calculated resistance to impact and concentrated load would not change once the floors were installed in the prototype vehicle; however, it was essential to verify the stiffness of the full size panels. Prévost staff were able to walk on the panels and feel the underfoot movement. Although only this qualitative testing was done, Prévost staff were very satisfied with the stiffness of the new floor designs. The consensus among Prévost staff was that Floor 2 had a slightly stiffer feel to it, but both floor designs were deemed acceptable.

One more test is still required of the floor designs before final selection: an acoustical analysis test. It was decided that, rather than perform the acoustical analysis in a laboratory environment, it would be performed on the roadworthy prototype vehicle. The overall acoustical properties of the floor are quite small when compared to the complete acoustical treatment of a completed vehicle. It is expected that a much more accurate representation of noise will be obtained from a full vehicle test. An outside firm will perform the acoustical test once the prototype vehicle is ready.

In addition to the sound dampening requirements, the panel must not create noise when walked on, especially in a hard-soled shoe. Floor 2 had a much more pronounced noise when walked on by Prévost staff.

With the detailed designs of the floor developed, fabricators were able to provide a much more accurate cost for the fabrication of the floor panels. The costs are provided in Table 7.1. As can be seen from the table, Floor 1 offers significant cost savings over Floor 2, but costs 11 percent more than the current plywood/steel floor. Again, it is expected that the cost of the new floors will be reduced when the process department completes its re-evaluation of the production cost associated with the installation of the new floor designs. The cost of Floor 2 was also much higher than predicted in Section 5.7. This was attributed to higher transportation costs and the exchange rate against the American dollar as the supplier of Floor 2 is in the United States.

A prototype vehicle could be outfitted with the new floor panels and road tested later in 2003.

Table 7.1: Refined Cost Analysis of the Final Floor Designs

Concept	Cost Increase
Floor 1	11%
Floor 2	37%

In the final analysis both floor designs performed well, meeting the floor requirements as identified in Table 4.1. Each configuration met the global and local design load requirement of the passenger floor. Both configurations offered roughly the same weight savings potential, but Floor 1 currently offers the lower cost increase to Prévost.

Floor 1 was selected for full-scale prototyping in a roadworthy vehicle. The expected completion date is later in 2003.

7.2 ROOF PROTOTYPE DEVELOPMENT

As a result of the detailed design of the roof, no one concept emerged as the preferred design choice for the roof. The one-piece composite roof module was the most cost effective and offered the greatest weight savings, but required the most in terms of capital costs to implement. In addition, the results of the physical testing showed that there were still some difficulties in infusing a part as complicated as a window post.

For the all-aluminium design, ALCAN has not finished the feasibility study of the mechanically fastened concept using the Alusuisse fabrication technique. Therefore, this design could not be completely assessed. To help in this assessment, Prévost had ordered a mock up of a System 2000 bus body from Prévost’s sister company, Säffle, in Sweden for evaluation before ALCAN became involved with the project.

Sections 7.2.1 to 7.2.3 describe the development of the prototypes of the roof designs. These prototype parts were not intended to be of production quality but instead to give manufacturers and Prévost a better understanding of fabrication techniques, handling, and fixation of the designs.

7.2.1 *Composite Roof Module*

As mentioned earlier, the composite roof module was prototyped. Although the part was roughly 10 ft. long, containing two passenger windows, it was decided that if this design were to move into production, the part would be made the full length of the vehicle. The decision was based on the difficulties in aligning many modules along the length of the vehicle, as well as the potential for water ingress between the modules. The fabricator delivered the part to Prévost, which then attached it to the vehicle cross-section mock up as discussed in Section 7.1 for the floor prototype.

The part as delivered to Prévost is shown in Figure 7.3. Prévost staff attached the part to the mock up. The part, even at only one quarter the length of a production part, was quite large, requiring innovative ways of handling and manoeuvring to be developed. The part was attached to the steel side trusses using a structural adhesive applied by hand.

Figure 7.3: Composite Roof Module Prototype

This component was not considered of production quality due to problems with the infusion process of such a large, complicated part. Therefore, the stiffness of the overall part was quite low. It is expected that as the production process is further refined and improved, the quality and stiffness of the module will improve, thereby meeting the requirements of the roof. This will of course be verified by physical testing when the final module is produced.

During the installation of the roof module part, certain areas of concern were raised:

- The side trusses must be maintained parallel before attachment of roof module;
- The bottom of the window posts must be maintained parallel before attachment to the side structure;
- Infrastructure needs to be developed to raise and move the roof module;
- The roof module must be attached after the floor has been installed (either permanent or temporary) to facilitate positioning of the module and application of the adhesive;
- The ability of the adhesive to remain in place without flowing or moving (Thixotropy) is an important factor in the assembly of the module;
- The adhesive application system must be on a sliding mechanism in order to apply adhesive along the entire length of the roof module; and
- The window hanger extrusion should be supplied to the roof module supplier so that it could be included in the lay-up rather than attached later.

In addition to manufacturing considerations, the large size of the roof module will pose challenges for storage and handling as well as transportation from the supplier to Prévost.

The completed mock up was internally outfitted with a vehicle interior and will be used as a demonstration-of-concept piece. The complete vehicle cross-section prototype is shown in Figure 7.4.

Figure 7.4: Completed Vehicle Cross-Section Prototype, Composite Roof Module and Floor Design 1

7.2.2 *Sandwich Panel Roof with Composite Window Post Modules*

The other leading roof design was the hybrid roof module approach where a sandwich panel would be made from aluminium skins over a structural core. The panel would be completely outfitted with extrusions during its fabrication, and the window posts would be changed from single steel posts to composite window modules. Structural adhesives would be used to attach the roof panel to the window modules and the window modules to the side truss. Based on this design, prototype parts were fabricated and installed onto the second mock up.

Since the final design was not selected for this concept, it is still undecided whether the skins will be made from aluminium or composite. Testing of the skins against required roof criteria such as impact from hail and walking loads have yet to be performed and it was certain that this would affect the choice of materials. Also, the final selection of the core material has yet to be completed. The sandwich panel chosen for the prototype section as determined from the global analysis described in Section 5.4.1 was 2 in. thick and was fabricated with aluminium skins. The final thickness of the roof was chosen based on meeting the thermal insulating requirements of the roof without the need for any additional insulation. Extrusions were embedded into the panel during the lay-up to receive the parcel rack as well as the window post modules.

Again, as with the composite roof module, this panel was not a production-quality part. The manufacturer had difficulties creating such a large curved sandwich panel and there were some problems with the adhesive. The completed panel is shown in Figure 7.5. The roof panel still requires improvements to the manufacturing technique and its detailed design before a production-quality part can be produced. However, Prévost has little doubt as to the feasibility of such a design. This design is well proven in European coaches and trains. A recent visit to ALCAN's 3D composite plant in Switzerland gave Prévost staff a first-hand view of such a panel in production for a similar application.

Figure 7.5: Completed Panel for the Roof

The window modules were fabricated using the same mould as the entire roof module, and are shown in Figure 7.6.

Figure 7.6: Infused Window Modules

The installation of this design onto the mock-up structure was very similar to that of the roof module design described in Section 7.2.1. The one obvious difference was that the window modules had to be first attached to the roof panel before being fitted to the mock up. To first attach the three components together, a jig was designed so that the parts remained in their proper positions while the adhesive cured. The production concerns with this design were the same as those in Section 7.2.1. The completed mock up section, including interior finishing, is presented in Figure 7.7.

Figure 7.7: Completed Mock-Up Section of the Sandwich Panel Roof Design

7.2.3 *Säffle System 2000 Bus Cross-Section Mock Up*

To evaluate the mechanically fastened concept, a complete vehicle cross section was ordered from Säffle. The mock up is shown in Figure 7.8. Although this is not a specific Prévost vehicle, it did give Prévost experience with the fabrication of bus body fabricated under such a system. The components were delivered in an unassembled state, which was then assembled by Prévost's prototyping shop.

Figure 7.8: Säffle System 2000 Bus Cross-Section Mock Up

As can be seen in Figure 7.9, this bus body is meant for a body-over-chassis application. The completed bus body is attached to a fully outfitted self-supporting chassis. The bending stiffness of the completed bus is a combination of the stiffness of the chassis and body. This is different than Prévost's coaches, where Prévost utilizes a complete integral structure for both body and structure. The delivered cross section is therefore not directly applicable to the Prévost line of coaches.

It did, however, allow Prévost to gain experience in the assembling of a mechano-type structure. The results of the ALCAN study will hopefully help envision a design using this fabrication technique specifically for a Prévost vehicle.

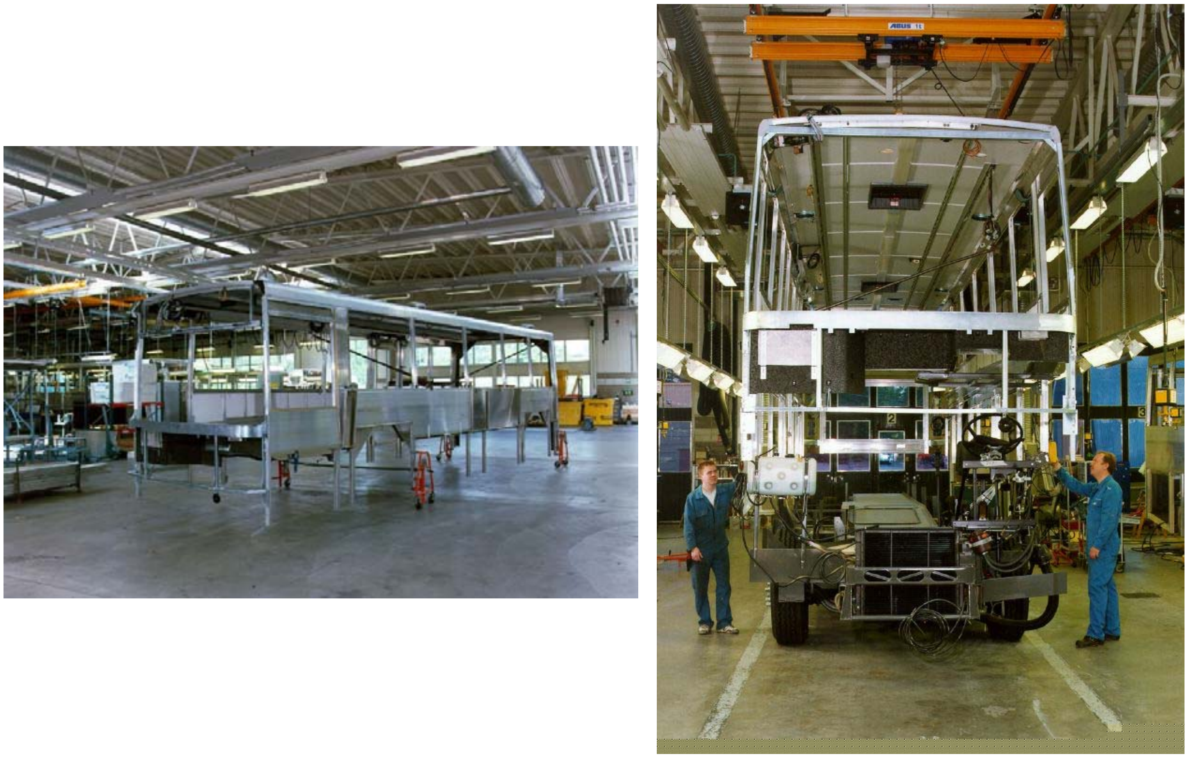


Figure 7.9: Example of the Säffle System 2000 Bus Structure
(Photo courtesy of Säffle Karosseri AB)

8. FUTURE AREAS OF CONSIDERATION

8.1 PHASE III – FUTURE VEHICLE SCOPE

The next phase in the advanced engineering project is the implementation of the components of Phase II into full-scale, roadworthy vehicle prototypes. As well, the project will also be a progression of the lightweight roof and floor designs produced in the Phase II project, with the goal of utilizing these designs to further develop and produce bus modules for specific options offered in Prévost vehicles. These customer-specific optional components include central doors and wheelchair lifts. Similar to the local option modules, global modules such as different roofs for motorhomes versus coaches will also be developed. Modules could be combined to offer greater flexibility for vehicle options as well as simplifying the manufacturing process.

Whereas the Phase II project focused more on weight reduction, the next phase in the project will broaden this focus to concentrate significantly on cost reduction. One of the most promising ways to save both cost and weight is to design parts that perform several functions at the same time. One ideal example of this from this phase was the new floor. The floor will now not only carry the passenger loads but also become a structural member in the frame of the vehicle. The designs will be developed with a goal to reduce the assembly time on the line and reduce the number of parts that need to be manufactured. This will also filter down to the purchasing department, where the number of parts that must be purchased will be substantially reduced.

This project is the logical progression of the Phase I and II weight reduction projects. It incorporates new and additional ideas that can ensure the success of the fabrication of lightweight modular vehicles and can improve on the goals of the production and purchasing/supply departments.

8.2 AREAS OF RESEARCH NEEDED IN INDUSTRY

Throughout the Phase II project Prévost has been on the leading edge of design. The proposed roof and floor designs utilize state-of-the-art manufacturing techniques and materials. As with any leading-edge technology design, limitations have been experienced in bringing the concepts from designs to prototypes. One such crucial area involves infusion technology for large parts. In addition to the roof and floor, the internal weight reduction initiatives at Prévost would benefit substantially from new manufacturing techniques and increased use of new lightweight materials. A list of areas in which Prévost would like to see industrial research performed to overcome these limitations is presented below. Work needs to be done by manufacturers and material producers to develop cost-effective processes for low volume applications such as buses.

The research areas include the following:

- Thin wall aluminium extrusions and large size aluminium extrusions;
- More precise extrusion, especially for open sections;
- Low -volume casting technology (aluminium, magnesium, Nodular Iron);
- Forging technology;
- Magnesium extrusions;
- Magnesium alloy behaviour, in case of vehicle fire (standard);
- High-tensile thin sheet steel welding;
- Infusion techniques for large parts;
- Lamination properties between carbon fibre and fibreglass;
- Composite pultrusion technology;
- Recyclability of composite material;
- Characterization of structural adhesives for similar and dissimilar materials;
- Atmospheric, galvanic, and crevice corrosion protection methods;
- Large sandwich panel technology, flat and curved; and
- Carbon fibre technology for low-volume commercial structural applications.

Prévost sees a great potential for weight savings in the areas described above. Considerable steps have been taken in Europe to reduce the weight of intercity buses, leading to the development of the CompoBus, BOVA Majiq, and D-Bus as described in Section 4. However, it is not only the bus industry that would benefit from this research, but all areas of the transportation sector. Low-volume manufacturers such as Aston Martin are already building vehicles out of carbon fibre and aluminium, but with extremely high costs. In addition, the large-volume manufacturer, Volvo Truck, has a very aggressive weight reduction initiative. To date, the weight of its vehicles has been reduced by 455 kg (1000 lb.). Prévost is very committed to lightweight vehicles and will continue the push the envelope of knowledge in order to achieve this.

9. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Based on the work performed during the Phase II advanced engineering project, significant weight savings were realized for the floor and roof of the Prévost Car intercity bus. The weight reduction objective of 50 percent was achieved through the production of a prototype of the new lightweight floor design and, based on the design work to date, will be achievable in the new lightweight roof design. Although the design of the roof has not yet been finalized, the overall project is still considered a great success. The average weight savings were 331 kg for the floor and 290 kg for the roof.

The final design of the floor met the objectives of the project. A sandwich panel was selected as the final design with a specific material chosen for the upper and lower skins. The final selection of the core material will be based on a future acoustical analysis and final determination of the production cost. Prototypes of the new floor panels have been fitted to representative mock-up sections of the bus with a roadworthy prototype vehicle anticipated late in 2003.

The development of the lightweight roof component also met the project objectives even though the final design had not been completed by the end of the project. Much of the design work was carried out such that the choice was narrowed to two potential candidates: an all-composite monocoque roof module and a sandwich roof panel supported on composite window post sections. Subsequent to this project, work will continue refining the design and working with suppliers to develop production-quality parts.

A potential design for producing lightweight intercity buses that was investigated during this project was an all aluminium-fastened concept. Some experience was gained with this technique through discussions and visits with Säffle in Europe and through the evaluation of a full-scale mock-up section supplied by Säffle. Advantages were discovered with this manufacturing technique for both weight reduction and flexibility for installation of customer-required options. To further investigate the potential of this type of design, a study was initiated with ALCAN. The results of the ALCAN study will greatly enhance the understanding of fabrication techniques utilizing aluminium and help to further evaluate this design.

One area of manufacturing within Canada that was seen as a challenge for fabricating lightweight roof components was in the infusion of large composite components. There are several American and European fabricators with this capability; however, it was felt that this is a resource that should be resident in Canada. With more emphasis expected on lightweight transportation materials, Canada and Canadian companies should consider gaining this expertise as a worthwhile investment.

In addition to the design and fabrication of lightweight floor and roof components, the potential future requirements for buses were also investigated. Specifically, these were the inclusion of seatbelts and the provision of rollover resistance of the bus body. Currently, regulations to implement these features do not exist. However, they may be forthcoming; therefore, consideration was given to these items for future bus designs. For any new design to withstand seatbelt loads, the new floor and seat track must be capable of accepting a seatbelt anchoring system. Similarly, the new roof design must have sufficient strength in the window posts and roof panel to carry a portion of the rollover load. Preliminary work was carried out to study these requirements; however, more detailed study is required.

It was anticipated that the continuation of the advanced engineering project would occur as the originally planned Phase III project. However, as a result of the work completed during this phase, a redefinition of Phase III has transpired. Throughout the design process the concept of lightweight modules became more prevalent and eventually was considered a requirement in any new vehicle design. This was because a modular approach allows for greater flexibility for manufacturing as well as installation of customer-required options. Consequently, the follow-on advanced engineering project evolved to develop option-specific modules that could be fitted to the various coach platforms.

Prévost Car is very committed to lightweight vehicles. In addition to the advanced engineering project, Prévost has an ongoing internal mandate to save 150 kg per year on the weight of intercity buses. This is achieved through component replacement, substitution, or re-design. As can be seen from the recent “levelling-off” of the overall bus weight, Prévost has had great success with this initiative.

The outcome of this phase of the advanced engineering project along with the other internal weight reduction programs will greatly enhance Prévost Car’s position as a premier North American intercity bus manufacturer. Although more work is needed in developing the final roof design, it will be continued within Prévost as an internal initiative. In addition, new projects show great promise in producing lightweight vehicles utilizing the designs of the Phase II project in combination with the newest ideas on the modular approach.

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