MANTA: Lightweight Concept Vehicle Design

Yuqing Zhou¹, Jeff Xu², Kazuhiro Saitou¹
¹ School of Engineering, University of Michigan
² School of Art and Design, University of Michigan
Executive Summary

With the proposed four weight reduction concepts, we expect the total curb weight reduction of ~20%, compared with the baseline design (from 3374lb to 2535lb). As a result, the expected MPG improvement is ~15% (from 22.5 to 25.7 (city) and 32.5 to 37.1 (high way)). The weight reduction breakdown is shown in Figure 1 below.

The windowless cabin concept relaxes the major constraint previously enforced on the body structure design, hence provides more open design space for potential weight reduction opportunities. The rear-facing detachable seat concept not only eliminates the conventional seat metal structures and adjustments, but presents a safer and more comfortable seat solution. The 1-2-1 tire layout design saves the weight of one of the heaviest components in the transmission system, the differential gear box, and brings the corresponding suspension downsize as well. Finally, the multi-material body structure design implements the idea of “right material in the right place”.

Weight Reduction Methodology

In this section, we propose four weight reduction methods, including 1) windowless cabin, 2) rear-facing detachable seat, 3) 1-2-1 tire layout, and 4) multi-material body structure. The expected weight saving is calculated based on the surveyed baseline model. For the sampled six current market sedan models (2012-2014), their average curb weight is 3374lb, with MPG (city) of 22.5 and MPG (high way) of 32.5.

1. Windowless Cabin (Expected weight saving: 373.39lb)

Recently, several airplane companies including Airbus, Spike Aerospace and Centre for Process Innovation have envisioned their next generation aircraft with the windowless fuselage concept (see Figure 2). Not only does this design provide the beautiful view of outside world to the passengers, but demonstrate huge potentials for weight reduction. By removing the windows
as a constraint, it allows the designers to design with more open spaces. For example, the fuselage can be designed as a lightweight and strong framework, mimicking the bone structures of birds, which is not possible with existing window layout.

![Image](image1.png)

(a) Airbus  (b) Spike Aerospace  (c) Centre for Process Innovation

**Figure 2** Next-generation airplane windowless design concepts.

Similar concept is also applicable to automotive structures. The constraint of having windows and doors in current automobiles enforces great challenges to the design of A/B/C pillars. Due to the limited possible number of crash load paths around the front window, the A pillars are usually designed to be overly strong (therefore heavy), so that the passenger cabin can be kept safe. This is especially the case for side crash as well. See **Figure 3** for the general crash load path of current automobile structures. If the constraint of having windows and doors is relaxed, it opens the design space and freedom, resulting in more complex load paths and optimized frame structures, which are expected to be much stronger and lighter.

![Image](image2.png)

(a) front crash load path  (b) side crash load path

**Figure 3** Crash load path for current automobile structures with windows and doors.

In addition to the weight reduction advantage, the safety issue of having glasses is another concern. About 7,800 vehicle occupants are killed each year after being ejected through side

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windows of tempered glass\(^3\). When a windshield is destroyed in the course of a rollover accident, the strength of the roof is instantly reduced by 33\(^4\).

The outside view will be projected to the digital display panels surrounding the entire cabin through series of wide-angle panoramic cameras mounted around the vehicle to provide uninterrupted 360 degree view, as virtual windows (Figure 4 (a)). Another solution is to use Google glass like virtual reality devices for drivers to get the outside view (Figure 4 (b-c)). For future autonomous vehicles, such outside view will even not be necessary.

![Virtual window](image1) ![Virtual reality device](image2) ![Google glass](image3)

**Figure 4** Virtual reality technologies to get the outside view of the vehicle.

The expected weight saving in this section is calculated by the material weight of glasses (90lb) and expected weight reduction of further optimized structure under the more flexible design space (30\% of the body weight, 283.39lb).

2. Seat Base/Chassis Integration, Rear Facing and Detachable Seat (Expected weight saving: 85.15lb)

During the 8th Annual Automotive Seating Innovators Summit (Detroit, 2014), two major future challenges of seat design were brought to the table. One of them is to use digital human body models to design the seat with robust human variability, so that the range of movement and the number of adjustments can be reduced to reduce the weight of the seat. The other major trend is the individualization, meaning customers want a seat that adjusts to them. To resolve both challenges, we propose the detachable seat concept. With this concept, all adjustments are eliminated and each seat is custom made to fit individual body.

For an automotive seat, only around 25\% of the weight is from foam pads and trim covers. The rest of the weight is metal structure and adjustments. In the past decade, engineers came up with new materials and mechanisms to reduce the seat structure weight from around 15kg to 10kg. However, the potential to further reduce the weight of seats is limited. Therefore, we propose the detachable seat concept. The structure part of the seat will be integrated into the

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vehicle cabin structures as a seat base. The foam pad portion of the seat will be custom made for each passenger and can be easily attached to any universal seat bases (similar to the child seat, see Figure 5). Since the foam pad of the seat is individually designed for each passenger, no adjustment is needed, therefore saves some additional weight.

![Image](a) Child seat ![Image](b) Rear facing

**Figure 5** Child seat design and enhanced safety with rear facing.

According to Henary et al.⁵, a child is five times safer riding rear-facing than forward facing. In April 2011, the American Academy of Pediatrics (AAP) recommends that children ride rear-facing until at least age 2. Watson et al.⁶ even suggests the use of rear-facing child seats for children under 4 years old. It is also not coincidence that all seats in military aircraft face the back of the plane. The reason of rear-facing for children is to reduce the chance of spinal injury, especially due to their relatively large head mass. Considering all advantages of rear-facing seat design, we propose that all seats except the driver’s should be rear-facing. One may argue that rear-facing seat will lead to higher chance of motion sickness. However, according to a Volvo’s recent survey, they looked at thousands of pre-scholars and found the same rate of motion sickness in those riding rear-facing as those riding forward-facing.

The expected weight saving in this section is calculated by the frame structure weight of five seats (5 * 17.03lb = 85.15lb).

### 3. 1-2-1 Tire Layout (Expected weight saving: 191.09lb)

To reduce the weight of transmission and suspension system, we propose a novel 1-2-1 tire layout design. The engine drives the rear wheel, and the two wheels on each side of the vehicle are for support purpose only (similar to the training wheels in bicycles). The front wheel is for steering. With this design, no differential gear package is necessary for the steering function. In addition, the suspension system can also be simplified thanks to the single wheel layout in both  

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front and rear. The suspension structure will be similar to the motorcycle swingarm, which is a much lighter design than traditional vehicle casting control arms.

The expected weight saving in this section is calculated by the weight of differentials (100lb) and 10% of the baseline suspension system (91.09lb).

4. Multi-Material Body Structure (Expected weight saving: 188.93lb)

In current market, most automotive body structures are made of steels. Recent trend of substituting mild steels with high strength steels have contributed to the weight reduction of the vehicle. More aggressive models use aluminum as the major materials (e.g. Ford F150, Tesla Model S). Some other advanced cars even have carbon fiber composite as the materials of their body structures and panels (e.g. BMW i3). Although different kinds of materials have been used in vehicle body structures, it is rare to see body structures made of multiple dissimilar materials due, in part, to the lack of welding techniques to join dissimilar materials efficiently in a cost effective manner. However, recent progress in technology development of dissimilar material joining process has showed some promising prospects, including, but not limited to, adhesive bonding, friction stir welding, and ultrasonic welding. Compared with structures made of similar classes of materials, the structures made of multiple materials with the right material in the right portion can provide huge potentials to further reduce the weight of the vehicle, which still meet the dynamic crash, static bending and torsion requirements. Though more detailed optimization and analysis is required, we preliminarily propose the frame structures made of the combination of high strength steel, aluminum and magnesium, and panels made of natural fiber reinforced composite (e.g. kenaf, bamboo). Some multi-material automotive body structure concepts have been investigated in the research phase, as shown in Figure 6 (a-b). Figure 6 (c) shows some natural fiber composites used in Mercedes-Benz E-Class components.


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The expected weight saving in this section is calculated as 20% of the existing steel model body weight (188.93lb).

**Bill of Materials**

<table>
<thead>
<tr>
<th>Category</th>
<th>Materials</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame structure</td>
<td>Combination of steel, aluminum, and magnesium</td>
<td>Right material in the right place</td>
</tr>
<tr>
<td>Panels</td>
<td>Natural fiber reinforced composite</td>
<td>E.g. kenaf, bamboo</td>
</tr>
</tbody>
</table>

**Required Manufacturing Processes**

The economic polymer composite manufacturing process is necessary for the mass production of natural fiber reinforced panels. Resin transfer molding (RTM) of carbon fiber composite has been adopted in the mass production of BMW i3 (2013), which might be a promising candidate. However, as for the natural fiber composite, a full understanding of its permeability property, degree of polymerization and crystallization is necessary before the development of mass production manufacturing process. In addition, due to the multi-material body frame structure concept, the efficient economic dissimilar material joining techniques are required to achieve the goal of “right material in the right place”.

**Passenger Safety**

<table>
<thead>
<tr>
<th></th>
<th>Body</th>
<th>Powertrain</th>
<th>Chassis/suspension</th>
<th>Interior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
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<td>New design</td>
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*Table 2* shows that the passenger safety is expected to be enhanced in two aspects of the proposed design. In the body structure category, thanks to the windowless concept, the crash path loads can be better distributed, and the design freedom of the frame structures are relaxed, which will also lead to a stronger passenger cabin zone. On the other hand, the design of rear-facing detachable seat will dramatically reduce the chance of spinal injury during crash.

**Innovative/Safety Component**
Figure 7 Self-evaluation spiderweb chat (-1: very conservative, 5: very innovative).

Potential Challenges

1. Lack of multi-material topology optimization method for the frame structure design under dynamic loading conditions;
2. Lack of design for manufacturing (DFM) guidelines for the design of components made of unconventional lightweight materials and manufacturing processes (e.g. resin transfer molding of composite);
3. Economic natural fiber composite manufacturing and dissimilar material joining techniques;
4. Dynamic and control system design optimization of 1-2-1 tire layout;
5. Economic virtual reality solution for the windowless cabin concept.
with the elimination of windows, the driver pilots MANTA with the help of virtual reality

having the right materials in the right places is crucial to maximizing safety while eliminating unnecessary weight. the frame is constructed from a combination of high-strength steel, aluminum, and magnesium while the body panels are crafted from natural fiber reinforced composites.

by turning all but the driver around, we greatly reduce the chances of injury during an accident.

all seats are fixed in place, eliminating the need for complex and heavy adjusters. the driver has a detachable seat that is fabricated to ensure maximal comfort and fitment.

a diamond shaped wheel layout helps to reduce weight by eliminating both the differential and simplifying the suspension setup.

without windows or conventional doors, the car can be thoroughly reinforced all around the passenger cabin. the character line eludes to the robust structural frame that lay beneath, further protection from a collision from any direction.
passengers enter and exit the vehicle through a back hatch that allows access to all five seats. The outside world is projected onto the interior surfaces, eliminating the need for heavy, less efficient and more costly digital screens. Each passenger faces backwards to reduce head and neck injuries during collisions. Each detachable and customizable seat is connected to the chassis and does not allow for back and forth adjustments, both the passenger seats and the cabin is design to accommodate the majority of body sizes with comfort.
the elimination of doors and windows allows for better optimized frame structures and complex load paths. and the absence of glass significantly lowers the chances of being injured by tempered glass or ejected from the vehicle.