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Adaptive Seat Cover for Motorsports and Daily Driving Situations

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Abstract

Automotive seat design presents an ongoing challenge as it involves balancing conflicting customer requirements, ranging from comfort and support to adaptability for diverse body types and custom-molded fit. Original equipment manufacturers often struggle to address the diverse needs dictated by the environment of use in automotive seat design. In response to these deficiencies, this paper employs the design thinking approach/model to explore the gaps in automotive seats comprehensively. The study provides valuable recommendations and documents the exploratory work carried out to bridge these gaps and enhance the overall automotive seat design. By utilizing design thinking principles, this research aims to pave the way for innovative solutions that meet the evolving demands of drivers, ensuring a more comfortable and safer driving experience for daily driving, and better performance for motorsports. Additionally, we present a comprehensive three-phase rapid prototyping approach to develop and showcase the functions of race car modifications, aiming to demonstrate their efficacy and gather valuable feedback from potential customers. By recognizing the significance of nurturing beginners' interest and skill development, the motorsports community can encourage wider participation and ensure a vibrant future for the sport.

Keywords

Design Research, Design Planning, Automotive, Engineering Design, Racing Accessories, Seat Design, Georgia Tech, HMI Lab, Industrial Design

1. Introduction

Motorsports and purpose-built racing cars have traditionally been perceived as an exclusive and inaccessible sport, largely due to substantial barriers to entry that dissuade many potential participants. These barriers encompass a wide array of challenges, such as the prohibitive costs associated with professional and pro-amateur motorsports, the intricacies of car and accessory customization, and the difficulty in securing sponsorships. However, despite these daunting obstacles, the enduring interest and unwavering passion exhibited by novice enthusiasts towards motorsports create a compelling market segment deserving of profound consideration. Grassroots motorsport clubs, sanctioned autocross classes involving unmodified daily driver vehicles, and the indispensable support provided by organizations like the Sports Car Club of America (SCCA) stand as evidence that there exists a profound human need to facilitate the learning trajectory of aspiring racers, guiding them from their humble beginnings as commercial road car drivers to the elevated status of pro-amateurs, equipped with bespoke track-only vehicles. Figure 1 shows a funny photo from the internet, a DHL Van driven aggressively on the Nürburgring, is this vehicle and the seats engineered to be track ready? This paper embarks on a comprehensive exploration of the barriers encountered by novice motorsport participants while examining the critical role played by existing platforms in nurturing their journey within the sport. By recognizing the intrinsic value of supporting novice enthusiasts, the motorsports community can pave the way for enhanced accessibility, fostering greater inclusivity and ensuring a vibrant and promising future for the sport.

The pursuit of a learning trajectory in motorsports poses a profound design challenge, particularly concerning the optimization of racing seats within commercial road cars. While standard road car seats are purpose-built for daily commuting, they prove inadequate for the demands of the racing environment, where drivers push vehicles to their limits under intense conditions of rapid acceleration, deceleration, and intensive cornering. This inherent limitation raises significant ergonomic and safety concerns, prompting a crucial question: How can we design a product that not only enhances the tracking experience but also ensures the utmost safety of drivers, all within a reasonable budget? Addressing this pivotal issue, our team embarks on a comprehensive research endeavor, exploring existing market solutions for racing seats and proposing innovative design ideas aimed at customizing seating for racing applications within the commercial road car market. By navigating this design challenge, we aspire to pave

Figure 1. DHL Van on Nürburgring. Track Ready?

the way for an enriched and secure racing experience, promoting accessibility and fostering broader engagement among novice enthusiasts in the exhilarating realm of motorsports.

Motorsport and daily driving represent two distinct realms, each serving disparate contexts and purposes. This divergence becomes evident when considering the contrasting design characteristics of seats tailored for these diverse applications. In sports cars and racing vehicles, seats prioritize tight body support under higher g-forces, aiming to keep drivers alert and engaged during intense maneuvers. These seats are often characterized by their stiffness and snug fit, albeit challenging for easy ingress and egress. Remarkably, in certain regions, installing racing seats in on-road vehicles may even be deemed illegal. Conversely, original equipment manufacturer (OEM) seats designed for commuter applications frequently fall short in providing adequate support, opting for softer and larger foam padding to prioritize driver comfort during regular driving. As a result, when OEM seats are employed in racing conditions, drivers find themselves shifting within the seats, necessitating counterbalancing against the forces to maintain position. The team faces an intriguing challenge: How can we bridge this divide and create a solution that offers enhanced support to novice racers who occasionally drive under track conditions, while ensuring comfort during regular road driving? In tackling this design conundrum, our research seeks to forge a path towards versatile seats that strike an ideal balance between optimal support and unrivaled comfort, catering to the needs of drivers transitioning between these dual environments with ease.

2. Design Research and Planning

2.1. Design Method

The team is following a design thinking process (shown in **Figure 2**) throughout the entire research, design, and testing phases of this project.

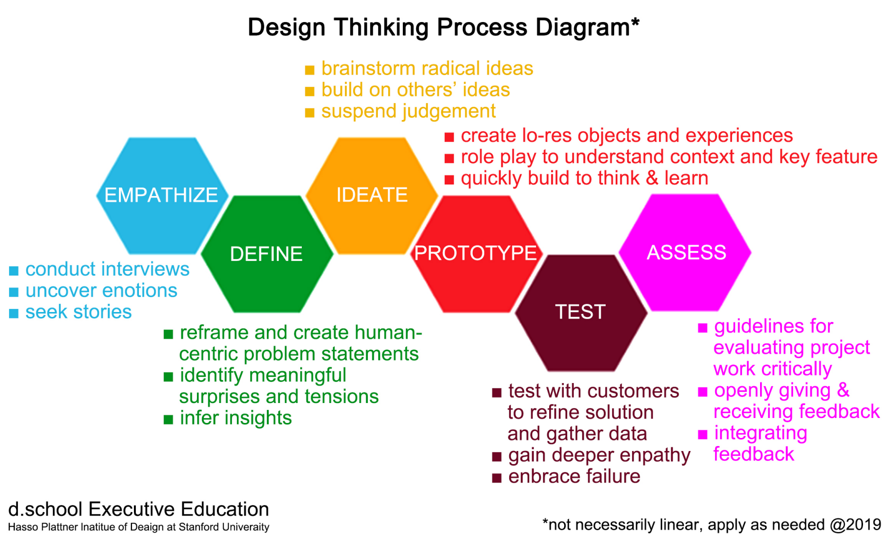

Figure 2. Design thinking process diagram [1].

2.2. General Market Research

The team embarked on the research phase with the primary purpose of identifying prior art, as well as gaining insights into the current offerings of major companies in the market. This comprehensive inquiry included patent research, examining existing products, competitive benchmarking, and conducting test drives at local car dealerships. By delving into these areas, the team aimed to ascertain the state-of-the-art technologies and products available, providing valuable context for the subsequent stages of the project.

2.3. Patent Research

This section of the research aims to discern the predicate technologies and prior art patents related to car seat comfort and safety considerations. The focus lies on examining patented technologies that have been developed to enhance the overall comfort and safety of car seats:

- Active seat bolster adjustment based on occupant pressure map and method [2].

This patent proposes an innovative method for adjusting seat bolsters in response to the occupant's pressure distribution on the seat surface. By analyzing the occupant's pressure map, the system can dynamically modify the seat bolster's shape to provide optimal support and comfort during different driving conditions.

- Sports car with synchronized seat height adjustment [3].

This patent introduces a sports car equipped with a synchronized seat height adjustment system. The system allows simultaneous height adjustment of both the driver and passenger seats, ensuring optimal visibility, ergonomics, and comfort for both occupants.

- Collapsible sports car [4].

This patent presents a design for a collapsible sports car that addresses safety concerns during accidents. The car's structure is engineered to absorb impact forces effectively, reducing the risk of injury to the occupants and enhancing overall crashworthiness.

- Noise-proof sports car seat [5].

This patent showcases a noise-proof sports car seat designed to minimize vibrations and noise transmitted to the driver and passengers. The seat's construction incorporates specialized materials and engineering techniques to create a quieter and more comfortable driving experience.

2.4. Customer Research

The team started customer research by interviewing drivers with track experiences, and here is the collected information from the participants:

2.4.1. Participant 1

Participant 1, who resided in the U.S. from 2015 to 2020 for college, possesses an impressive collection of sports cars. During his time in the U.S., he owned and experienced driving several notable models, including a Porsche Panamera, BMW M3, and BMW M6, all of which he took to renowned tracks such as Road Atlanta, VIR, and COTA. Presently residing in China, Participant 1 continues to maintain a fervent interest in sports cars, with a collection that includes a Porsche 911 Targa, Porsche Panamera, BMW M3, and Ferrari 812.

Interview Insights:

Participant 1, standing at a height of approximately 167 cm (5'5"), encounters challenges with the limited adjustability of height in most of his owned sports cars. To compensate for this, he utilizes a cushion between himself and the seats, albeit experiencing certain drawbacks. The cushion diminishes the effectiveness of the seat's side support, resulting in inadequate hip support during aggressive driving, leading to undesired sliding within the seat. While the smart side bolsters from Mercedes are beneficial during constant turns, their behavior tends to lag during switchback turns, running counter to the intended side. Furthermore, the smart bolsters engage even during slow, gentle turns where they are unnecessary, causing discomfort in daily driving situations.

2.4.2. Participant 2

Participant 2's involvement in motorsports extends back to his time in the U.S. from 2015 to 2020, where he had the opportunity to race on numerous renowned tracks, including Road Atlanta, VIR, and COTA. Additionally, his passion for racing led him to Europe on multiple occasions, where he experienced the thrill of tracks such as Nürburgring and SPA. Presently residing in China, Participant 2 actively competes as a GT3 Driver, accumulating a wealth of racing and driving experience across diverse regions. His remarkable journey spans various vehicle types, ranging from trucks to GT3 Race cars, underscoring his versatility and profound engagement in the motorsport's realm.

Interview Insights:

Participant 2's experience with several Porsche 911 GT3s across different regions reveals intriguing variations in seat size. Comparing the U.S., Chinese, and European versions, he observed that the U.S. market offers the widest seats, whereas the Chinese market provides the tightest fit. While he comfortably fits into the European and Chinese GT3 seats, he finds the U.S. seats too wide for his stature (approximately 5'7").

Expressing a desire for a custom seat cover, Participant 2 emphasizes the importance of comfort functions and enhanced support. However, he remains mindful of the weight implications, recognizing that different vehicles have varying weight sensitivity. For GT3 Race cars, where substantial support is already provided, he seeks additional comfort features like cooling and heating, with a maximum weight limit of 2 kg. Conversely, for his modified M3, he prioritizes increased support, additional cushioning, and heating and cooling features, but the seat cover should not exceed 3 kg in weight.

Assessing sports car offerings, Participant 2 appreciates Ferrari's seats for their superior comfort, characterized by ample cushioning and superior conformity to the driver's body. Nonetheless, he acknowledges the high cost of Ferrari seats, designed to cater to specific customers at the time of ordering, making them a luxurious yet exclusive option.

2.4.3. Participant 3 (Local Speed Shop Manager)

The purpose of interviewing Participant 3 extends beyond gathering insights solely from customers. As the manager of a local speed shop with extensive experience in automotive modifying and tuning, Participant 3 possesses a unique perspective. By engaging with them, the research aims to tap into the knowledge gained from daily interactions with various customers and their diverse feedback about the products. Additionally, Participant 3's exposure to a wide range of automotive products surpasses that of most customers, making their input invaluable in understanding product performance, customer preferences, and identifying potential areas of improvement.

Interview Insights:

The speed shop offers a range of esteemed brands, including RECARO, Sparco, and MOMO, with RECARO emerging as the most preferred choice among their clientele. Customers gravitate towards RECARO seats due to their competitive pricing, superior quality, and extensive collaborations with numerous car manufacturers, encompassing models like Ford Focus, Subaru, Mazda, and more.

When it comes to recommendations, the shop discourages the use of bucket seats or excessively stiff seating for road-driving vehicles. These seats feature a markedly aggressive posture, leading to stiff contact surfaces with the body, lacking adjustable comfort settings. While heated seats hold limited importance in Atlanta's moderate climate, ventilated or cooled seats prove highly advantageous during extended drives or track sessions. The prospect of having cooling seats is particularly appealing when navigating mountainous terrain or engaging in track activities, promoting enhanced driver comfort and focus.

Moreover, the participant has expressed dissatisfaction with some OEM seats featuring advanced features, such as dynamic adjustment functionalities designed to better support users during cornering. However, there are significant lag issues and inherent limitations hindering the proper functioning of these features, undermining their intended purpose.

2.5. Prior Work Research

According to a customer study related to comfort features of car seats done by Du Xuxu [6], 60.16% of customers choose headrest support, 56.91% of customers consider vibration resistance. Button touch quality, lumbar support, length of back support cushioning, leg and feet room are around 50% - 40%, heated and cooled seats are around 39.02%, shown in **Figure 3**.

2.5.1. Competitive Benchmarking: Car Companies

The team benchmarked the following car companies' offerings for OEM stock

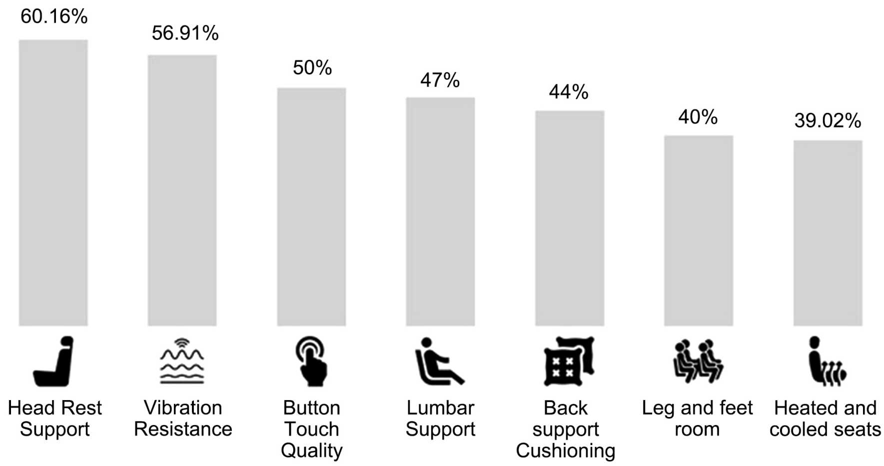

Figure 3. Customer research of comfort features on car seats.

seating. Looking at Mercedes-Benz, a luxury automaker, the most common features offered in their seats are heated, ventilated seats and seat massage. For higher-end S-class sedans, they offer a feature named Hot Stone Massage Seats, which is a combination of a heated feature and active air pockets. With special programs, the active air pockets and heating mat simulates a hot stone massage while driving to relax the driver [7]. For the new Mercedes EQS model, a new electric flagship sedan, the massage function is more advanced. If the car is not in drive, the seat reclines and heats up, and the active air pockets on the back, lumbar and side bolster interact with the driver to create a relaxing experience inside the vehicle. A new function called "Energizing Comfort" is also offered in this model, which is a combination of ambient lights, video, spatial sounds system, cooled air, and active air pockets inside the seats [8].

Porsche, a luxury sports vehicle manufacturer, they are offering a new 3D printed seating zone option for some models [9]. The central section of the seat, which is the seat pan and the backrest cushions are partly produced by 3D printing technology based on the driver's body, and the seat will conform to the customer's body while providing better ventilation.

For 2021's new BMW M4 and M3, BMW offers carbon sports seats as an option for $3800 in the U.S. market [10]. The seat pan height is much lower than the standard road seats, which puts the driver's H-point more in line with the center of gravity of the vehicle, and makes the driver feel more connected to the car, providing more feedback from the road through the seat. The sports seats are narrower in general, fitting the s drivers' hip, waist, and shoulder more tightly, which can help the driver hold their body position against strong g-forces. However, they are not comfortable in terms of long-distance driving. They are very stiff to sit in and do not offer much support in the lower back area. The seats are also more difficult to get in and out of compared to normal seats.

2.5.2. Competitive Benchmarking: Aftermarket Modification

Although these features are offered by OEMs; they are usually confined to the most expensive or luxury packages in each model. According to research, the package that includes both heated and ventilated seats ranges from $2300 to $3800. The team started researching if it would be cheaper to add these functions by modification. The costs are presented in **Figure 4**.

From **Figure 4**, it's clear that the cost to add these features through aftermarket modification would cost more for customers.

2.5.3. Competitive Benchmarking: Current Offerings

In the subsequent section, the team carried out benchmarking to evaluate existing offerings that aim to address the dual concerns of comfort and racing features within a single car seat. The analysis encompassed Stock Car seats, which are the original seats provided with the car from the factory, either designed or selected from car seat manufacturers by the automakers.

Stock Car seats offer distinct advantages as well as limitations in their design. On the positive side, these seats result in lower costs for both manufacturers and customers due to their efficient mass production. They are tailored to deliver a comfortable driving experience for daily use, facilitating convenient ingress and egress for drivers. Additionally, the design caters to the average body size, accommodating a wide range of users with varying physical attributes.

Conversely, Stock Car seats exhibit certain drawbacks that warrant consideration. Notably, they face limitations in accommodating extreme body sizes, thus lacking versatility in meeting the diverse needs of customers with unique physical requirements. During aggressive driving maneuvers, particularly in the hip and shoulder regions, these seats may fall short in providing adequate support, potentially affecting driver comfort and safety. Moreover, the selected materials for seat construction may not offer sufficient friction, potentially compromising the optimal tracking experience. Further limitations arise in the realm of functionality, with the number and extent of available features often determined by manufacturer market decisions, thereby reducing customization options for users.

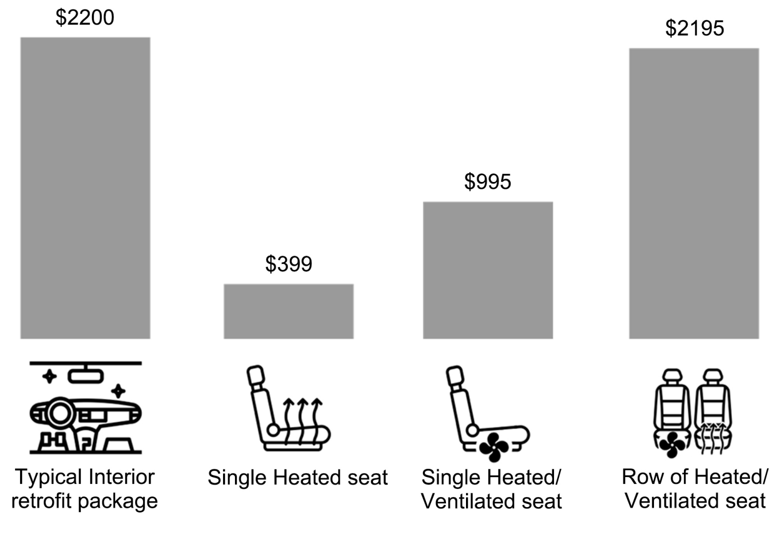

Figure 4. Cost for aftermarket modifications [11].

Another noteworthy limitation is that Stock Car seats may not be compatible with various seat belt configurations, usually restricted to three-point belts in compliance with local laws and regulations. Consequently, racing harnesses, which offer enhanced safety in racing environments, are not permissible for road car usage in the U.S. due to seat belt laws and regulations [12]. These aspects underline the need for careful consideration of Stock Car seats' suitability based on individual preferences and driving requirements.

Aftermarket car seats, provided by companies specializing in seats for specific uses such as racing, off-roading, etc. [13] present a distinct option for drivers seeking enhanced performance and support. The advantages of aftermarket car seats are manifold: they offer superior support and restriction to the driver's body during aggressive driving, aiding focus on the track when required. Additionally, these seats are designed to accommodate racing harnesses, offering 4-point, 5-point, and 6-point options. Beyond functionality, aftermarket seats exude a more professional and appealing appearance, lending a professional edge to the driving experience. Furthermore, these seats often come in varying sizes, allowing for a better fit tailored to individual customers, surpassing the limitations of stock seats.

However, there are certain drawbacks associated with aftermarket car seats that warrant consideration. Primarily, the adoption of sports seats entails an additional expense for drivers, with top-rated sports seats in the market being the NRG Innovations Alcantara Bucket Racing Seats priced at $360, Sparco Sprint Racing Bucket Seat at $373.57, and MOMO Daytona 1074BLK Racing Seats at $719.95 [13]. Moreover, the extra support provided by sports seats on the track may result in diminished comfort for daily driving purposes, as the seats often feature reduced cushioning for weight savings and better support. Limited adjustability is another downside, with bucket seats offering no adjustments at all. The material choice for sports seats, Alcantara, provides considerable friction, which may not be the most comfortable for extended sitting. Additionally, sports seats with larger or higher leg support might pose challenges during ingress and egress for users.

2.5.4. Advanced Motorsports Driver Solution Interview and Benchmarking

The team conducted benchmarking to explore advanced solutions catering to customers with a higher budget and a strong emphasis on performance and enjoyment. This initiative aimed to gain insights into the prevailing optimized solutions, enabling the team to discern the most suitable options. The benchmarking process involved analyzing current solutions used by customers who own separate track and commuting vehicles, as gleaned from posts from SCCA, shown in **Figure 5** [14]. Additionally, interviews were conducted with car enthusiasts, including speed shop owner and customers shown in **Figure 6**, track drivers shown in **Figure 7** and GT3 pro drivers shown in **Figure 8**, to further enrich the research findings.

SCCA

Sports Car Club of America®

Figure 5. Logo of SCCA.

Figure 6. Photo of interview local speed shop.

Figure 7. Photo of participant 1 driving his modified KTM.

Figure 8. Photo of participant 2 preparing for GT3 Racing.

The market offers a specialized category of track-only cars, unsuitable for road use in most cases. These track-focused road cars begin at a base price of $30,000, equipped with specially tuned engines, transmissions, and stiffer suspensions optimized for track driving. Ensuring safety, these cars require 4-point or 6-point harnesses and helmets for drivers on all tracks. The track-only focus is further emphasized by the inclusion of special aero kits. For drivers with a budget of approximately $100,000, options expand to include vehicles like the BMW M4 and Porsche 911, boasting enhanced track capabilities. At higher budgets, GT3 vehicles become accessible, either directly from manufacturers or through used purchases, which command a price of around $300,000. However, it is essential to note that the actual cost of owning and running a GT3 car surpasses the initial purchase price. Additional expenses encompass premium tires priced between $2000 to $5000, along with specialized high-octane fuel (95 octane or higher). Excluding potential damages and the need to hire technicians, these supplementary costs must be factored in [15].

Considering these considerations, our research team's challenge lies in designing a seating device that can enhance accessibility to these advanced features for the market while simultaneously delivering an improved and immersive racing experience. The objective is to offer innovative solutions that cater to the unique demands of track-focused driving, enhancing the overall enjoyment and performance for drivers.

2.6. Design Ethic and Cultural Differences

This project was considered using an inclusive design approach. The team wanted to design for users from every region, but different customers from different regional areas expressed different opinions about this product. During interviewing, it was found that most of the drivers in the U.S. do not prefer using any type of seat covers or aftermarkets products on their vehicle, including seat covers, steering wheel covers, and even aftermarket floor mats. However, in Asian markets, car seat covers, steering wheel cover, and aftermarket floor mats are considered necessities after getting a new car. This is a huge cultural and habit difference for aftermarket products between these two regions based on customer interviews. Based on data from Global Market Insight, shown in **Figure 9** [16]. The Asia Pacific accounts for over 40% of the entire market of seat covers and would be growing significantly during 2020 to 2026. However, the seat cover market in North America is also growing rapidly between 2019 to 2026. This indicates that customers would be adapting their preferences, and more seat covers would be accepted for customers in the North America region.

2.7. Stakeholders and Needs

The proposed car seat solution targets customers who occasionally engage in track driving experiences using their daily-driven vehicles. While these vehicles primarily serve commuting purposes, the product's design places significant

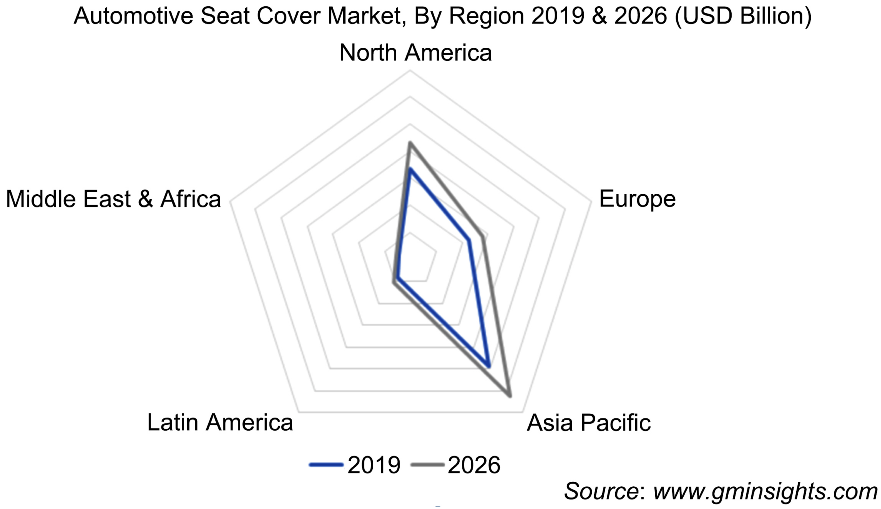

Figure 9. Automotive seat cover market by region.

emphasis on ensuring optimal comfort for users. Simultaneously, paramount importance is given to safety aspects, as the seat must provide sufficient support to keep the driver firmly in place during aggressive driving maneuvers.

3. Design Process

3.1. Ideation Process

The team commenced the design ideation phase to address the identified problem. Figure 10 exhibits a selection of ideation sketches generated, primarily focusing on modifications to the automotive seat design. The proposed solutions revolve around incorporating additional cushioning, enhanced adjustability, and interactive elements to elevate the comfort level of the seats.

Drawing insights from comprehensive research and market analysis, the team arrived at a conclusive decision to pursue the direction of designing a seat cover solution.

3.2. Design Considerations

3.2.1. Seat Map

Based on driving experience, the weight of the driver is not equally distributed in a car seat, based on a study from Novel De shown in Figure 11 [17], we found the pressure distribution applied to a typical seat.

To better understand the seating pressure distribution, as an empirical test, the team wetted pants, and placed layers of absorbent sheets (napkins) on car seats. The wet area of each layer of the napkins is recorded and shown in Figure 12.

3.2.2. Material Choice

To make the product more comfortable while providing enough support, the team purchased different types of material including cardboard, packaging foam, polyurethane foam (in different densities: extra soft, medium, and medium hard), polyethylene foam and Alcantara sheets as shown in Figure 13.

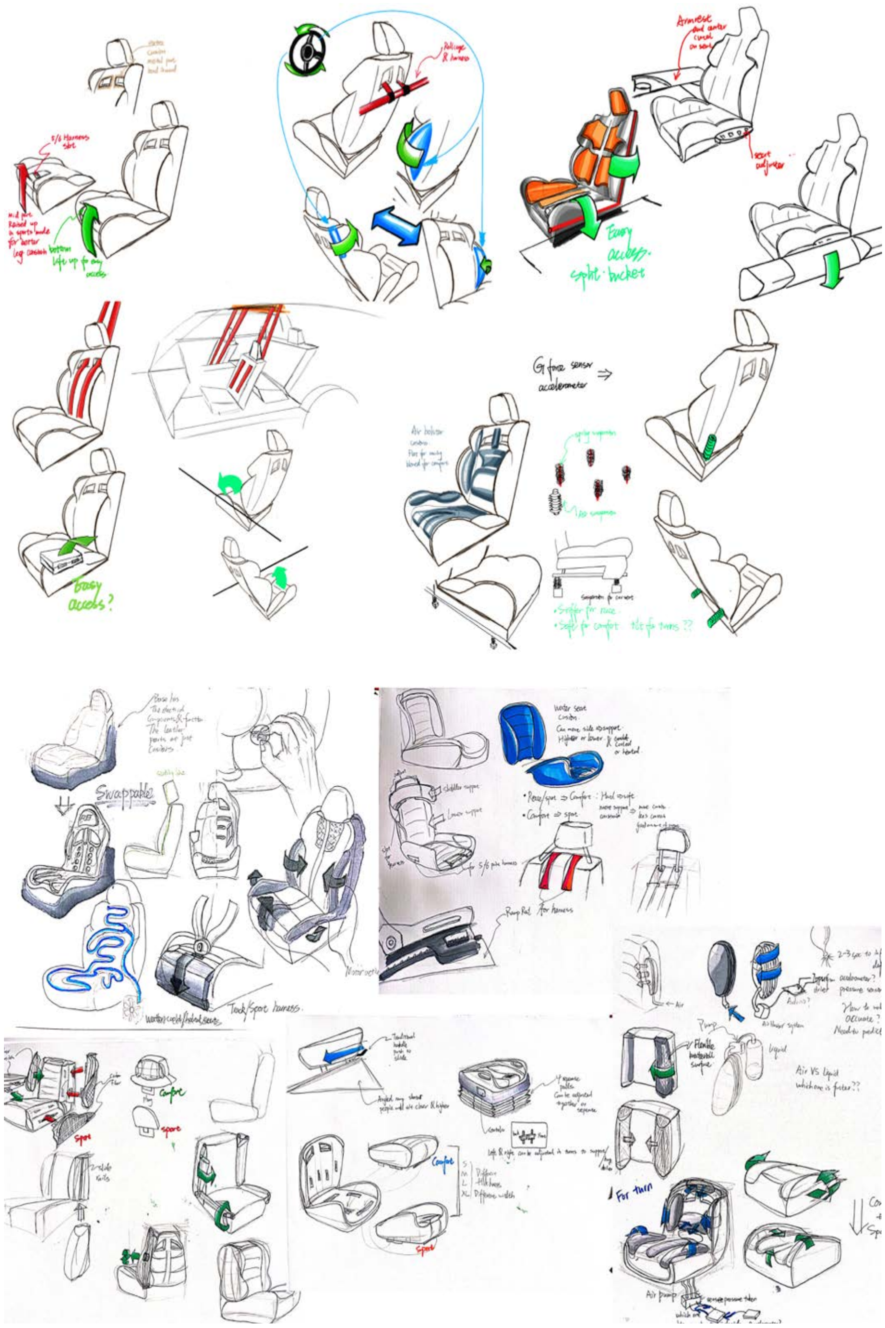

Figure 10. Ideation sketches.

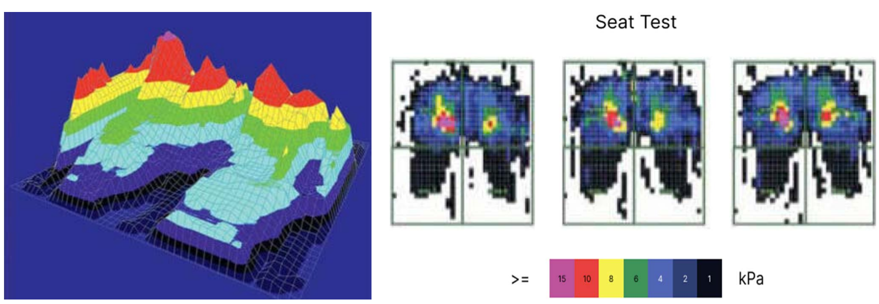

Figure 11. Car seat pressure distribution.

3.2.3. Ergonomics

In order to provide a better seating position and posture for drivers, ergonomics must be considered as shown in Figure 14. The product must consider the H-point, center of gravity and distance of the driver to the center of the steering wheel, and so on during the design process.

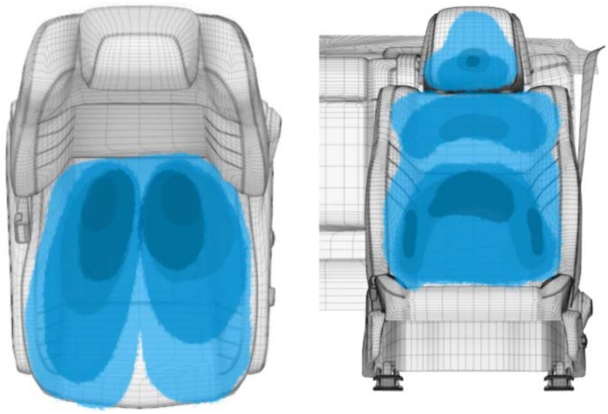

Figure 12. Car seat pressure distribution measurement.

Figure 13. Prototyping foam.

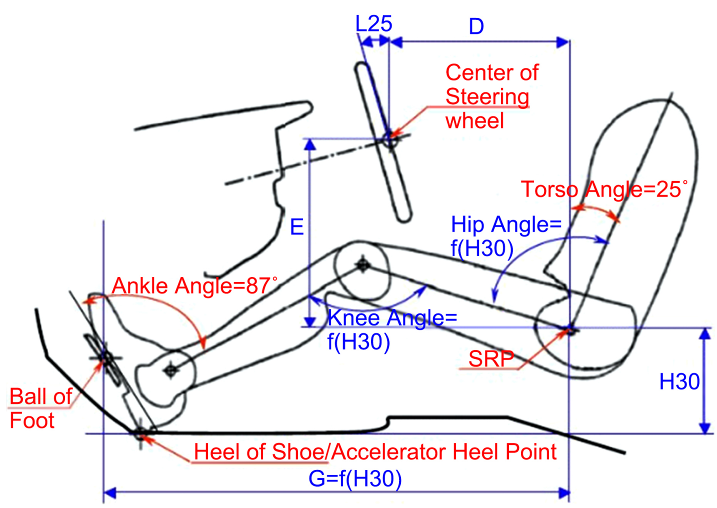

Figure 14. Ergonomic graphic, h-point.

4. Prototyping

4.1. Prototyping and Build Phase I

During this phase, the team developed low-fidelity models using chipboard and packaging foam to assess essential design features of the product. Figure 15 illustrates the initial version of the prototype.

The primary objective of the initial model was to evaluate the positioning of the support structures and assess whether they offered sufficient support to the user. For this phase, dense and thick foam was utilized deliberately to ensure that the user could distinctly feel the foam in contrast to the cardboard component. This choice allowed the team to identify and rectify any inaccuracies in the placement of cushioning for subsequent iterations.

The Version 2 low-fidelity seat mapping model, shown in Figure 16 is constructed using cardboard and is derived through 3D scanning of the body surface. This scanning process aims to ascertain the appropriate rise of the seating position, enabling the provision of enhanced support for the driver. The primary objective of this prototype is to assess the acceptability of the additional height for drivers in exchange for a more tightly contoured seat pan.

Figure 15. Version 1: Low-fidelity model and testing.

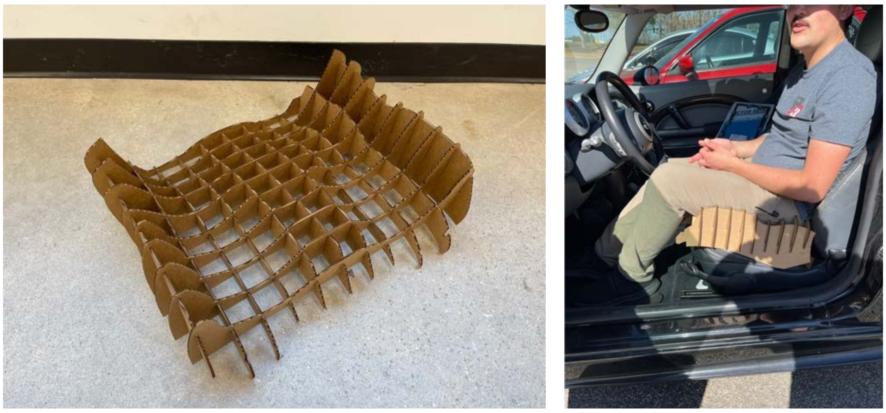

Figure 16. Version 2: Low-fidelity seat mapping model and testing.

Testing Feedback and Results from Phase 1

Throughout the testing phase of all prototypes, the team adheres to the process of participatory testing, wherein the product is handed over to the user with only essential instructions provided. In this context, during the testing process, the prototypes were simply handed to users with the information that they are intended for use in vehicles to enhance comfort and provide additional support.

Upon evaluating the first prototype, the user initially placed the pieces upside down, resulting in an unpleasant experience. Realizing the orientation error, the user promptly corrected it and proceeded to test the prototype in both a comfort sedan and an aftermarket sports seat. The first prototype displayed satisfactory performance with the comfort sedan seats, providing extra support albeit with some discomfort due to the density of the foam. However, its compatibility with the aftermarket sports seats was limited by the presence of aggressive side bolsters, which, when combined with the additional layer, rendered the seat too narrow and highly uncomfortable.

Regarding the second version, it exhibited commendable performance with the comfort seat, offering gentle support without causing disruptions. Nonetheless, the prototype's waffled structure, constructed from cardboard, led to discomfort from the edges after prolonged use. Although the structure elevated the driver by approximately 3 inches, this was deemed acceptable, as users could easily adjust their normal sitting height slightly lower to accommodate the change.

4.2. Prototyping and Build Phase 2

During this phase, several mechanisms aimed at enhancing comfort were incorporated into the prototype and subsequently tested to assess their feasibility.

4.2.1. Air Pump Side Bolster (Shown in Figure 17)

This function is designed to allow users to adjust the height of side bolster with an air pump mechanism. The system requires the user to press the button, and the air pump would start to pump air into the balloon, which served as the bolster (air pocket) in the prototype.

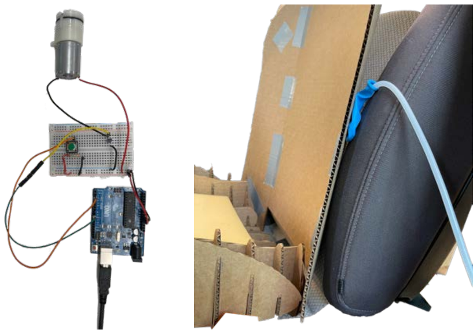

Figure 17. Air pump side bolster.

4.2.2. Folding Mechanism (Shown in Figure 18)

This mechanism was designed to fold and unfold to adjust the height of the support, and they could be applied to various areas of the seat, including lumbar, side bolster, and leg support. In the middle was a server motor, and strings were attached to it. After getting the command, the server motor would rotate, and the strings were pulled. The structure of the folding mechanism allows the moving part to squeeze itself after the strings were pulled.

4.2.3. Pressure Sensor (Shown in Figure 19)

These sensors were added to detect where more pressure is applied to the seat while the car is in motion and going through corners. It can serve as an input to the system. Based on the pressure level sensed by the sensor, the side bolsters could adjust accordingly while driving through turns to provide better support to the driver.

4.2.4. Fans for Ventilated Function and Cushioning (Shown in Figure 20)

As mentioned from the research, cushioning and ventilated feature of car seats are important in terms of comfort. More cushioning was added by adding layers of different density foams to contact areas. Fans were added to the seat cover in a separate location and angled to provide better circulation.

4.2.5. Testing Feedback and Results from Phase 2

These prototypes were only tested in the GM HMI lab with users and peer industrial designers. The air pump system worked very well during the testing process because it showed the idea of using air pockets and air pump to provide support to the driver well, and the structure did not break during the testing sessions. Whereas the folding mechanism was also rated as a good idea, but the durability of the structure made of cardboard was not satisfying.

The pressure sensors were places on each side, and the system could determine which side of the seat was applied with more pressure caused by motion of the driver in the seat. The sensors could successfully record the pressure level, and if the system could have the ability to determine the range of the pressure level. If the pressure level is too high which means the driver is leaning towards one side more than the other, it would trigger the mechanisms to support the driver to the other direction.

Figure 18. Folding mechanism support.

Figure 19. Pressure sensing system and testing.

Figure 20. Cushioning and fans added.

The users could feel the breeze from the ventilation system very well once they are turned on. The angles of the fans were very effective. The layers of different density of foam were also effective as the harder layer would filter out the sharp edges of the waffle structure, and the softer layers were adding comfort level to the structure.

4.3. Prototyping and Build Phase 3

In this phase, the final high-fidelity model was built for user testing.

4.3.1. Parametric 3D Model

In order to have the structure better fit the user and the vehicle, the model of the seat cover was developed in Fusion 360 parametrically, shown in Figure 21, such that it could be adjusted based on: 1) the size of the car seat and 2) the hip dimension of the driver. This feature would make the product more comfortable for customers, and more suitable for most car seats. The cushioning level can also be adjusted based on the preference of different stiffnesses.

The final high-fidelity prototype, shown in Figure 22, consists of the 3D parametric model that is sliced into a waffle structure from Slicer for Fusion 360, different density foams for optimized cushioning, a fan system for ventilation, air pump system with 3D printed housing (shown in Figure 23), and pressure sensor system. The seat cover is covered with Alcantara fabric for aesthetics and friction coefficient, as shown in Figure 24.

4.3.2. Testing Feedback and Results

The final prototype underwent initial testing by peer industrial designers and was subsequently subjected to evaluation by professionals in the car modification industry at the speed shop. By fortuitous circumstances, a gathering of Mini Cooper owners took place at the speed shop, and they were invited to participate in the final model's testing alongside the speed shop manager. The prototype garnered high acceptance among the users and the manager, eliciting their valuable feedback on potential product development and presenting unique use cases not previously considered during the design process.

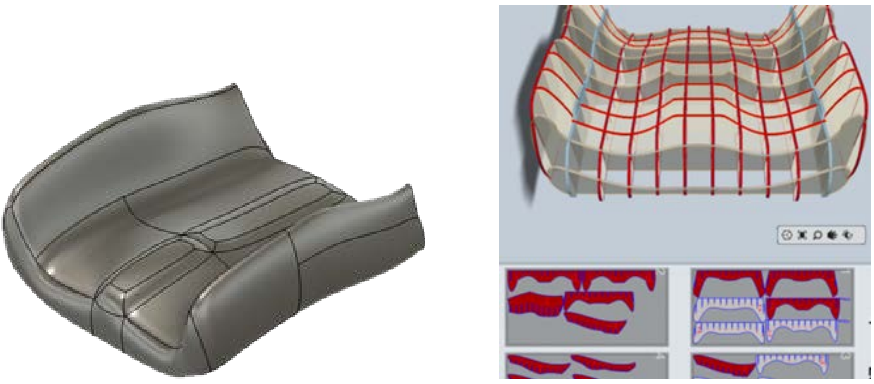

Figure 21. Parametric modeled seat cover.

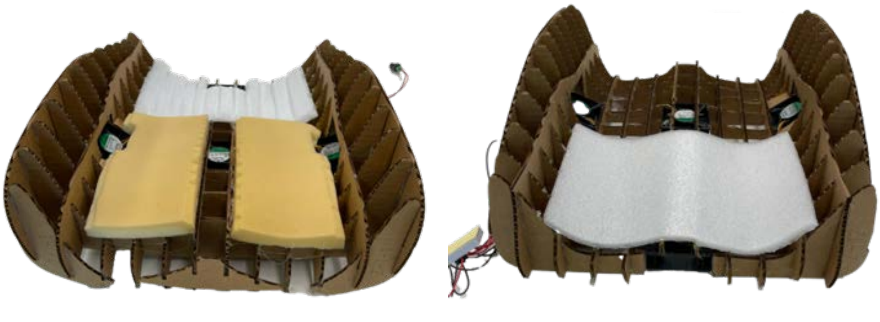

Figure 22. Final high-fidelity prototype exposed.

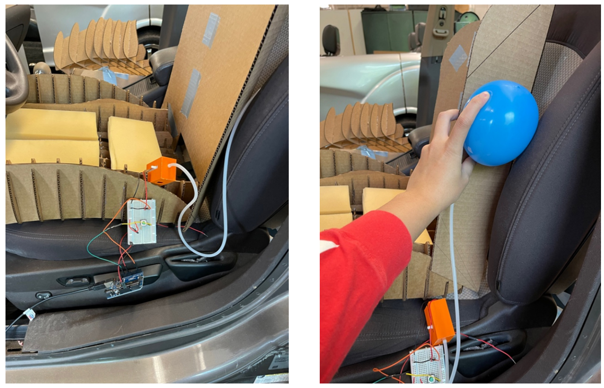

Figure 23. Final high-fidelity prototype air pump system.

Figure 24. Final high-fidelity prototype and testing.

As previously stated, the research team diligently adhered to the participatory testing approach throughout the entire testing process. The participants were informed about the prototype's purpose, and the instructions for the participatory testing were presented. Subsequently, the prototype was provided to the participants for evaluation and the method of "Think out loud" was encouraged during testing. They were encouraged to assess various aspects of the comfort level, whether by simply sitting on it and exploring its functions or by installing it on their car seats and taking the vehicle for a drive. The participants were actively engaged in rating the comfort and functional aspects, and they were also welcomed to offer feedback and pose questions, fostering opportunities for further improvement of the prototype. Table 1 shows the testing results from 13 participants. As depicted in the table, the prototype received favorable ratings in terms of overall comfort from 13 participants. Particularly, the cushioning aspect earned the highest rating, attributable to its well-designed ergonomic positioning. The support was also rated positively, with participants finding it comfortable during initial use. However, when subjected to long-term sitting testing (exceeding 5 minutes), some participants observed a slight decline in support comfort, with stiffness becoming noticeable over time. On the other hand, the cooling function garnered positive feedback from most participants, who recognized its utility for both intensive driving and daily commuting. As for the adjustable bolster feature, although demonstrated to the participants, it received the lowest rating due to concerns about its reliability in the prototype version.

Table 1. Testing results rating of the final prototype.

Features and Ratings	Rating out of 5 Total Number of Participants: 13
General Comfort Level	4.3
Cushioning	4.7
Support	4.5
Sitting for 5 minutes	3.3
Cooling Function	4.1
Bolster Adjustment (Demo)	2.1

In addition to the ratings obtained from the participants' testing, several insights from the participants and user error were recorded, proving invaluable and providing valuable guidance for future enhancements of the design:

- An observed issue with the prototype pertained to its orientation, as participants noted a lack of clear indicators specifying which side should be placed against the back of the seat, leading to confusion during testing.
- A matter of contention among users revolved around the material of the cover. While some individuals commended its ability to offer ample friction, preventing slipping in seats, others expressed dissatisfaction, stating that it lacked sufficient friction for prevention. Additionally, some users wearing shorts found the material to be pleasant, yet they expressed concerns about potential sweat absorption and subsequent odors over time.
- The positioning of the control for activating the ventilated function, which was situated on the right side of the prototype. Participants expressed that this placement posed a challenge for drivers as it could be obscured by the seatbelt, making it difficult to access during use.
- A noteworthy observation was that certain participants exhibited unfamiliarity with current technology and experienced some distress upon turning on the ventilation fans.
- The participants have articulated their views on the bolster function, acknowledging its novelty and appeal. However, some raised concerns regarding its potential to become bothersome while driving and its possible contribution to accidents, particularly if drivers are not well-acquainted with this feature.

Furthermore, the prototype was showcased at the Launchpad design showcase event hosted by the Georgia Tech School of Industrial Design. The event drew the attendance of numerous participants from design, engineering, and business backgrounds, many of whom expressed keen interest in the prototype and offered valuable insights and feedback (**Figure 25**).

Figure 25. Testing of final high-fidelity prototype during launchpad event.

5. Further Development of Product and Use Case Scenarios

The project was developed within a limited timeframe, leaving scope for future improvements and iterations. Initially, the current parametric model was constructed using Fusion 360, but its potential enhancement lies in the utilization of Rhino and Grasshopper. Implementing these tools would allow for the incorporation of anchor points on the model, enabling easy adjustments to dimensions based on users' preferences and anthropometrics.

Another aspect deserving attention is the improvement of the reliability of the adjustable features mechanism. Presently, these features are designed as proof of concept and require refinement to ensure their manufacturability and longevity.

Throughout the testing phase of the final prototype, valuable suggestions emerged from professional industrial designers, users, and retailers. One noteworthy suggestion is to explore the Asia market, as car owners in this region frequently acquire seat covers to protect their seats. Introducing the product in this market is expected to garner quicker acceptance due to existing seat cover usage.

Additionally, the possibility of manufacturing the air bolster using heat forming or vacuum-forming was raised by another designer, presenting an intriguing avenue for implementation.

During testing at the speed shop, users introduced intriguing use cases that were not initially considered during the design process. Notably, the product could cater to vehicles that are frequently driven by multiple individuals with varying body dimensions. For instance, a Mini Cooper owner mentioned that the car is used daily by his wife and occasionally by him on the track. The seats, designed for track use, are too narrow for comfortable daily commuting for him, while simultaneously being too wide for his wife's satisfaction. The design presented herein could offer an optimal solution to accommodate the needs of such customers effectively.

In summary, the design encompasses both the current and potential user groups:

First Group: People who drive their daily driver on the track occasionally.

This segment comprises individuals who occasionally take their daily drivers to the track. For this group, the product serves the dual purpose of optimizing comfort during commuting while providing the necessary support and safety for track driving experiences.

Second Group: Enthusiasts who spend substantial time on the track and possess a separate vehicle for daily commuting and track use.

This user group comprises individuals who frequently engage in track driving and maintain separate vehicles for their daily commute and track activities. The product's lightweight design makes it an ideal complement to their sports seats, seamlessly fitting within the existing configuration. Additionally, the product offers the advantages of extra cushioning, support, and the option for heating and ventilation, catering to the specific needs of track enthusiasts during their intensive driving sessions.

Third Group: Customers not satisfied with their OEM car seats.

The third user group consists of customers dissatisfied with their OEM car seats, seeking enhanced support and comfort features, even if they do not engage in track driving.

Fourth Group: Customers with body sizes at the extreme ends of the anthropomorphic scale.

This category comprises customers with body sizes falling at the extreme ends of the anthropomorphic scale. It includes scenarios such as the case of a short friend, as well as instances highlighted by a speed shop customer, where a shorter wife and taller husband must share the same car despite their size differences. For these users, the design offers a viable solution to accommodate diverse body dimensions and ensure an optimal driving experience.

6. Conclusions

In conclusion, the final prototype testing has substantiated that a product of this nature holds significant potential to enhance the overall driving experience for users. Particularly, it proves beneficial for vehicles that lack adequate comfort during daily commuting, yet necessitate superior support and focus when used on the track. The product effectively provides the desired additional support to drivers during cornering and turning, while simultaneously offering comfort-enhancing features, including layered cushioning, ventilation, and even active side bolstering.

Considering the constraints imposed by the timing of the research project, there remains ample scope for further improvements in the product's execution and implementation. For instance, the active side bolster function can be further enhanced by adopting a more reliable mechanism than the current ones in place. With a dedication to continuous refinement and evaluation of the concept, the research team aims to propel this innovation toward its optimal realization and greater potential in the realm of driving comfort and performance enhancement.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Design Thinking Models. Empathize@IT. https://empathizeit.com/design-thinking-models-stanford-d-school/

[2] Boccuccia, D., Senatore, A., Jaranson, J.W. and Calderon, A.A. (2019) Active Seat Bolster Adjustment Based on Occupant Pressure Map and Method. US Patent No. US10464456B2. https://patents.google.com/patent/US10464456B2/en/

[3] Ahnert, S., Newhard, D., Saville, D.S. and Iv, J.J.C.A. (2010) Sportwagen mit synchronisierter Sitzhöheneinstellung. Germany Patent No. DE102009036249A1. https://patentimages.storage.googleapis.com/de/6c/11/a75108dccc0f9c/DE102009036249A1.pdf

[4] Hartenstine, C.M., Newhard, D.N. and Ransil, M.J. (2003) Collapsible Sports Car. Germany Patent No. DE10318917A1. https://patents.google.com/patent/DE10318917A1/en?q=sports+car+seat&oq=sports+car+seat

[5] Cai, Y. (2021) Noise-Proof Sports Car Seat. China Patent No. CN213322781U. https://patents.google.com/patent/CN213322781U/en?q=%E2%80%A2+Noise-proof+sports+car+seat.&oq=%E2%80%A2Noise-proof+sports+car+seat

[6] Tian, D.D. (2014) Design Research of Automotive Seating based on Ergonomics. PC Fan, No. 3, 108. https://xueshu.baidu.com/usercenter/paper/show?paperid=949644d333d8af230d07091375985b03

[7] Chakravarty, S. (2013) Get A Hot Stone Massage with Aroma Therapy along and a Lot More Pampering in the 2014 Mercedes S-Class. Luxury Launches. https://luxurylaunches.com/transport/2014-mercedes-benz-s-class-massage.php

[8] Mercedes-Benz of Scottsdale (Director) (2021) Mercedes-Benz Interior Fabric Choices Explained from Mercedes Benz of Scottsdale. https://www.youtube.com/watch?v=NUg4EIzC6BA

[9] Sales Launch for Innovative 3D-Printed Bodyform Full Bucket Seat. Porsche Newsroom. https://newsroom.porsche.com/en/2021/products/porsche-innovative-3d-print-bodyform-full-bucket-seat-sales-launch-26060.html

[10] DeMattia, N. (2021) Are the BMW M Carbon Bucket Seats Worth the Money? BMW BLOG. https://www.bmwblog.com/2021/06/18/are-the-bmw-m-carbon-bucket-seats-worth-the-money/

[11] Digital Editors (2021) Can You Add Aftermarket Heated and Cooled Seats to Your Car? MotorBiscuit. https://www.motorbiscuit.com/add-aftermarket-heated-cooled-seats-car/

[12] Seat Belt Laws. U.S. Department of Transportation. https://www.transportation.gov/mission/health/seat-belt-laws

[13] Hurlin, T. (2023) Best Racing Seats for 2023. Forbes Wheels. https://www.forbes.com/wheels/accessories/best-racing-seats/

[14] Login Required. SCCA. https://my.scca.com/eweb/DynamicPage.aspx?WebCode=LoginRequired&expires=yes&Site=SCCA

[15] So, You Want to Go GT3 Racing? Part 1. Dailysportscar.com. https://www.dailysportscar.com/2020/06/22/so-you-want-to-go-gt3-racing-part-1.html

[16] Automotive Seat Covers Market Share—Industry Size Report 2026. Global Market Insights Inc. https://www.gminsights.com/industry-analysis/automotive-seat-covers-market

[17] Car Seat Pressure Distribution Measurement. Novel.de. https://www.novel.de/products/pliance/car-seat-pressure-distribution-measurement/