Design and Fabrication of Remote-Controlled Car

Keval Babu[1], Rachel Deghuee[2], Rushil Batra[3], Tiankai Chen[4], Abhimanyu Singh Bhakuni[5]

Abstract

The objective of this paper is to report the design and fabrication process of one remote-controlled (RC) car with a common swappable control box that can be transferred from one car to another. The purpose of the paper was to understand and apply the principles of design for manufacturing (DFM) and design for assembly (DFA). Each car had to be made according to the design and manufacturing guidelines provided. The paper culminates in a relay race where participants showcase the design attributes such as speed, reliability, and durability of their o;cars by racing them around the track. This report begins by defining the design objectives, detailed design explanations, and challenges faced and overcome throughout the paper.

Keywords: RC, Car, DFA, DFM, Manufacturing

1. Introduction

Race Design Rules

The cars must comply with specified size limitations and identical designs, incorporating at least one of the designated manufacturing processes such as thermoforming, sheet metal forming, and machining [1][2]. Various components like the chassis, wheels, tires, and control box must adhere to specific fabrication guidelines, while assembly is restricted to mechanical fasteners only, excluding items like duct tape and Velcro.Detailed guidelines are as follows:

- Cars must adhere to size limitations of 11” x 12” x 11”
- Each car must be identical in design
- Each car must incorporate at least one of the following manufacturing processes: thermoforming, sheet metal forming, and machining
- The chassis will be cut from an aluminum sheet (maximum thickness: 0.25")
- Maximum tire diameter: 4” (maximum waterjet cut time: 45 sec per tire)
- Cars shall be covered with a continuous thermoformed shell
- The battery, motor controller, transponder, receiver, and servo must be located in the control box
- All assembly must be performed using mechanical fasteners only. Duct tape, Velcro, or similar products are generally not allowed
- The transponder must be mounted horizontally, no higher than 15 cm (6 in) from the track
- No metal or carbon fiber is placed between the transponder and the track, and that the transponder is not directly mounted to the metal chassis

Design Requirements

For the research project, five key design functional requirements were identified that guided all subsequent design decisions. Each design methodology was evaluated based on functional analysis to determine the best option. The key design requirements are as follows:

1. **Simple to Manufacture & Assemble:** Car components should be easy and quick to manufacture and assemble with the resources available at the LMP shop. Design for manufacturability principles governed the use of standard components like standard size mechanical fasteners and standard manufacturing and assembly tools. Prioritizing ease of manufacturing and assembly was crucial to limit complexity and minimize the manufacturing lead time for mass production.

2. **Swiftly Interchangeable Control Box (GoodyBox):** The control box change-out time was considered vital for determining the race outcome. The control box should be easily transferable between cars with minimal time elapsed and should remain locked throughout the race.

3. **Excellent Stability and Maneuverability:** Car stability and maneuverability were essential for accurately steering the car around the race track without losing control. The design stage considered the effect of track obstacles like mines and humps on overall car control. The car should have a low Center of Gravity (CG) and even weight distribution to ensure better stability and maneuverability.

4. **Structural Durability:** The car should withstand impacts from humps, mines, and crashes on the race track. A low CG would reduce the probability of the car toppling at corners, humps, or mines. The chassis should be designed to avoid any irreparable damage to the car.

5. **Compact, Creative & Aesthetic Design:** The vehicle was required to stand out and be easy to differentiate among other cars. It needed to be compact, creative, and aesthetically pleasing. The overall size and aesthetics of the car depended on the thermoform shell's design.

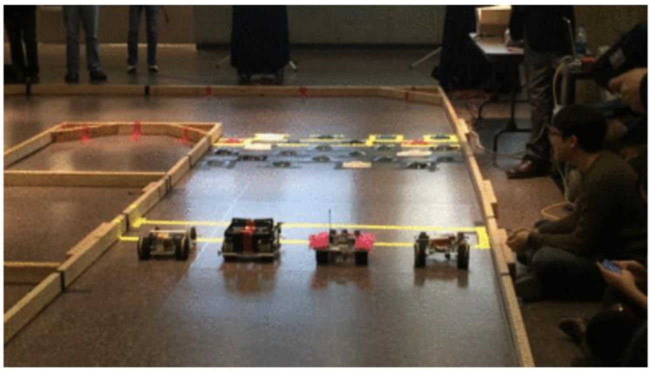

Figure 1: RC Car Race Track[1]

2. Design of Sub-assemblies

The car design comprised six major sub-assemblies: steering, chassis, control box, shell/body, suspension, and drivetrain.

(a) Steering

The steering system in any automobile application consists of various components working together to enable the vehicle to follow its desired course. For this research project, several design requirements were established for the steering mechanism:

1. **Turning Radius:** Footage from previous races revealed that the cars were unable to complete a full circle within the minimum width of the track. This posed a potential hazard for performance on race day,

especially in the event of a collision causing a car to turn in the opposite direction. To mitigate this risk, the maximum turning radius for the car was limited to approximately 2.5 feet.

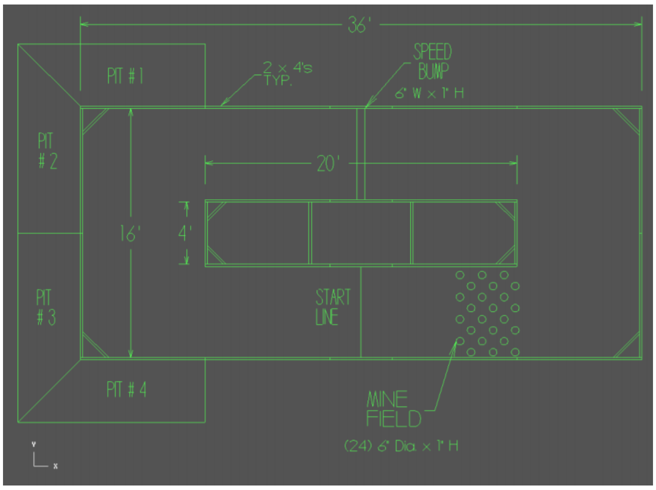

Figure 2: Track Layout

2. **Flexibility:** Due to the lack of quantifiable data on traction and steering performance, it was decided that the design should be flexible enough to incorporate any variations and allow for fine-tuning during the testing phase.

3. **Responsiveness:** The steering assembly needed to be sufficiently responsive to ensure improved handling of the vehicle at high speeds.

In designing the steering system, functionality took precedence over all other considerations. The design of linkages and their relationship with overall vehicle geometry was based on Ackermann geometry.

The minimum track (l) of the vehicle was constrained by the size of the battery and the available shell molds. This track, along with the angle of the steering arm on the knuckle, determined the vehicle's wheelbase (w). The required turning angles were established based on the desired turning radius. After setting the vehicle size constraints, several alternatives for the steering mechanism were considered. To introduce flexibility into the assembly, it was decided to use two wires to transfer motion from the steering fork to the wheel-knuckle assembly. This approach could potentially improve responsiveness by providing adequate flexure to the linkage.

A fork, fork mount for the chassis, and a servo attachment were subsequently designed, considering all necessary requirements. The fork design was finalized with the consideration that the GoodyBox would be assembled from the top during the race.

(b) Chassis

The primary focus in designing the chassis was to ensure it provided structural integrity to the car and acted as a hub to integrate all sub-systems. After reviewing videos from previous years' races, the decision was made to equip the chassis with front, rear, and side-impact members to protect the tires and control box from potential damage during the race. In terms of utility, the front and side impact members also served as mounting locations for the thermoform shells. After encountering issues with the first prototype, hole locations and sizes were standardized for the chassis. Additionally, the chassis weight was optimized to improve handling, reduce the tendency to topple, and enhance acceleration on straight sections of the track.

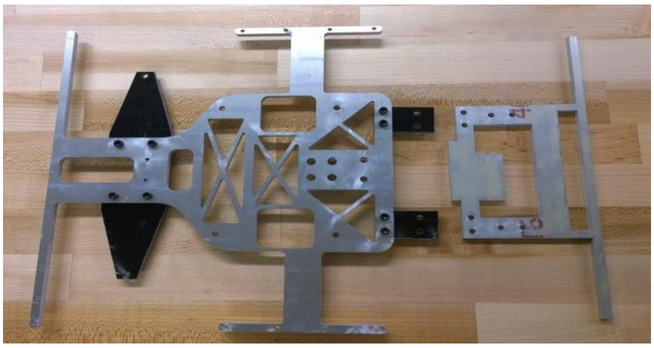

Figure 3: Chassis First build prototype

(c) Control Box

The control box, dubbed the "GoodyBox," was designed to hold the electrical components that needed to be transferred between cars during the race. It was decided that it would be water jetted out of aluminum sheet metal and then bent to shape to conform with the sheet metal project requirement.

The transponder was mounted on the bottom to save space and allow it to interact with the race monitoring equipment. A corresponding hole in the chassis allowed the GoodyBox to remain flush.

Initially, two or more alignment cylinders were considered to guide the box down. However, the number of parts was reduced by changing the alignment feature to a square. A square pin limits two degrees of freedom, so the box will not rotate as it is lowered onto the chassis. To reduce active manufacturing time and enable a more exotic shape, the alignment column was 3D printed, resulting in an elliptical alignment pin. A draft was added to the column to increase ingress speed [3]. The alignment column was moved towards the front of the chassis because the servo rotating the steering fork would induce a counter-action in the GoodyBox, causing it to shift. The alignment column anchored it in the front.

The primary attachment mechanism was the banana plugs located at the rear of the chassis. As the GoodyBox was lowered over the alignment column, the banana plugs would mate and secure it. Neodymium magnets were also used as an additional anchoring feature to reduce the effects of vibration and servo movement.

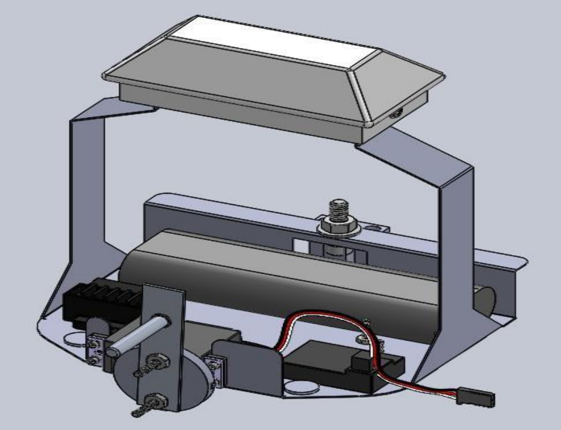

Figure 4: Control GoodyBox

(d) Thermoform Shell

The "elcamino" thermoform was selected because it resembled a car, provided ample interior volume, and had its tallest area centered. Old race videos showed that winning teams could transfer their electronics box between cars very quickly. Concerns arose about the time needed to unlatch the thermoform, remove the electric box, and re-latch it, so efforts were made to minimize the motions required for the transfer. Although cutting a hole in the thermoform for easy ingress/egress was initially considered, the requirement specified that the shell must be complete when the box is installed. Therefore, the tops of all thermoforms were cut off and a complementary top was attached to the GoodyBox. To swap the GoodyBox, it only needed to be removed, taking the top of the thermoform with it. Black plastic was used for the car bodies and clear plastic for the lid. The clear plastic lid allowed for visibility inside the car to ensure proper alignment.

Figure 5: Iteration of Thermoformed shells

(e) Suspension

Various designs for the suspension systems were considered. The suspension system needed to be robust and capable of absorbing vibrations to ensure smooth car operation. Inspired by the previous year's design, options included pneumatic/hydraulic suspensions, spring suspensions, or flexure suspensions. Key design functional requirements indicated that manufacturing pneumatic suspensions would be overly complex and would not provide a significant advantage in the race. Spring suspensions were a viable option but required lead time to procure from external suppliers. For the prototype, experimentation with flexure suspensions made from 1/8" Delrin was pursued. Subsequent testing revealed that Delrin was easy to manufacture and met the requirements for damping vibrations for smooth car operations.

Two different sets of suspensions were used in the car design. The front suspensions were designed to be significantly longer than the rear suspensions to provide more flexure for the front wheels. This design aimed to absorb most of the initial vibrations when the car encountered a hump or obstacle. The suspensions were also designed to integrate easily with the chosen steering mechanism without interfering with its operations. The rear suspension additionally served as a bridge connection between the front and rear chassis components.

(f) Drivetrain

The drivetrain subassembly consists of the motor, motor mount, drive shaft, axle mounts, self-lubricating bearings, rear chassis, and wheels. A direct gear drive was chosen for its simplicity, compactness, positive drive capability, and higher efficiency compared to belt drive. The direct gear drivetrain helped reduce speed and increase torque. The motor mount secured the motor to the rear chassis at an appropriate height to ensure good gear contact between the pinion and spur gear. Designed for flexibility, the motor mount featured slotted screw holes that allowed for the adjustment of motor orientation and height as needed [3].

The rear chassis included two slotted screw holes to adjust the center-to-center distance between the pinion and spur gear, achieving optimal gear contact. It was recognized that assembling and adjusting the motor and motor mount subassembly after press-fitting the rear wheels onto the drive shaft was mechanically and ergonomically challenging. To address this issue, the assembly sequence was revised. The motor and motor mount subassembly were installed first on the rear chassis, and the rear wheels were press-fitted at the end.

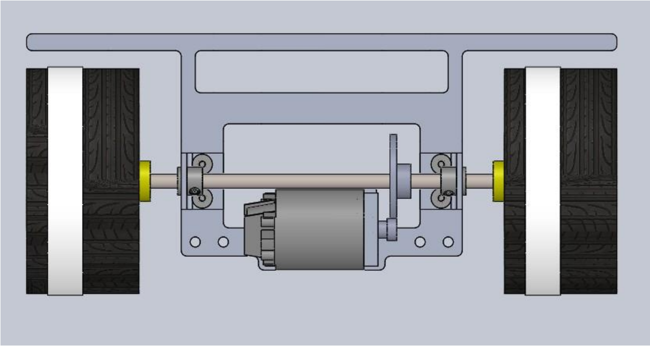

Figure 6:Drivetrain rear assembly (top view)

Manufacturing processes were evaluated and selected based on four main attributes: Rate, Cost, Quality, and Flexibility. The quality of each component was determined by its criticality. High flexibility in manufacturing processes was necessary to make quick modifications according to design iterations. Considering the mass manufacturability of all components, the rate of a process was crucial as it governed the lead time. The manufacturing processes for each component are listed in table 1 below.

Table 1: Manufacturing Process Selection

Steering				
Process	**Rate**	**Cost**	**Quality**	**Flexibility**
SLA	Low	High	High	High
Sheet Metal (Stamp & Shear)	High	Low	Moderate	Moderate
Wire Bending	Low	Low	Moderate	High
Machining	Moderate	Moderate	High	High
Chassis				
Water-jet cutting	High	Moderate	Moderate	High
GoodyBox				
Water-jet cutting	High	Moderate	Moderate	High
Sheet Metal (Bending)	High	Low	Moderate	Moderate
Shell				

Thermoforming	High	Low	Moderate	Low
Suspension				
Water-jet cutting	High	Moderate	Moderate	High
Drivetrain				
Machining	Moderate	Moderate	Moderate	High

Figure 7: Finished five RC cars

Overall, the car performed as intended. However, driving over obstacles revealed more failure modes than anticipated during the design phase. A better attachment mechanism than the banana plugs could have been chosen. During testing, issues with consistently powering the motor arose, as the banana plugs were short-circuiting due to the metallic chassis. If the project were to be completed again, the banana plugs would be mounted to a plastic ferrule and another attachment mechanism designed to hold the box in place. Additionally, the banana plugs, being the lowest points of the car, interfered repeatedly with track obstacles. When approaching obstacles too quickly, the banana plugs suffered an impact, and when trying to cross obstacles at a slower speed, the vehicle got stuck.

Variations between the thermoforms made it difficult to tell if the GoodyBox was fully inserted, even after looking through the windscreen. This was compensated for mid-race by testing the servo and motor before setting the car on the racetrack.

Using piano wire for the steering attachment proved effective and secure throughout the race. However, it took considerable time to adjust and tune, so using a single water-jetted attachment would have eliminated components and simplified the process.

3. Conclusions

In conclusion, the research project demonstrated the intricate process of designing, fabricating, and testing a remote-controlled car, emphasizing principles of design for manufacturing (DFM) and design for assembly (DFA). The project incorporated key aspects such as chassis design for structural integrity, an efficient drivetrain, robust suspension systems, and the innovative GoodyBox control box. Each component was carefully evaluated for its manufacturing process, with decisions driven by considerations of rate, cost, quality, and flexibility.

The adherence to manufacturing guidelines and the implementation of impact protection measures proved crucial in enhancing the car's durability and performance. Despite encountering unforeseen challenges, such as issues with the primary attachment mechanism and variations in thermoform alignment, adjustments were made to improve the overall design. The experience underscored the importance of flexibility and adaptability in the engineering design process.

The project's success was marked by the car's ability to perform as intended while highlighting areas for future improvement. The lessons learned from this project provide valuable insights into optimizing design and manufacturing processes for similar engineering challenges. The findings and methodologies outlined in this paper contribute to the broader understanding of effective design practices in competitive engineering environments.

REFERENCES

[1] "Race Day Details," Massachusetts Institute of Technology. [Online]. Available: https://web.mit.edu/2.810/www/race.html.

[2] "Team Project Details," Massachusetts Institute of Technology. [Online]. Available: https://web.mit.edu/2.810/www/proj-details.html.

[3] "Design Rules for Machining," *Product Design for Manufacture and Assembly*, G. Boothroyd, P. Dewhurst, W. Knight, Dekker, 1994.