MCG 4322[A]
FSAE Concepts Report
FSAE 2

by

AbdalAziz AlGhoul (300005268)

Hasan Shahzad (300001167)

Hisham Ali (300010128)

Peter Saroufim (300015864)

Munir Alsafi (300013845)

University of Ottawa

Department of Mechanical Engineering

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Professor: Mihaita Matei

Design TA: Nathaniel Mailhot

Marking TA: Ahmed Taimah

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Chapter 1

Project Charter

1.1 Mandate

Formula SAE (Society of Automotive Engineers) is a series of international competitions in which university teams compete to design and manufacture the best performing race cars. Our design team has been approached by a car manufacturer and contracted to develop a small electric Formula-style race car. The prototype should have high performance and be sufficiently durable to successfully complete all the static and dynamic events at the Formula SAE competitions. The prototype will be evaluated as it must follow all Formula SAE rules and regulations.

1.2 Requirements

1. The tractive system must be completely isolated from the chassis and any other conductive parts of the vehicle.

2. The tractive system motor(s) must be connected to the accumulator through a motor controller.

3. Only electrical motors of any type are allowed and the number of motors is not limited.

4. All accumulator containers must be designed to withstand forces from deceleration in all directions.

5. The accumulator container(s) must be completely closed at all times without the need to install extra protective covers.

6. Exposed high speed final drivetrain equipment must be fitted with scatter shields that may be composed of multiple pieces.

7. Coolant for electric motors and accumulators must be either plain water with no additives or oil.

8. The braking system must be operated by a single control and act on all four wheels. It must have two independent hydraulic circuits that have their own fluid reserve.

9. Vehicles may have either dry or wet tires.

10. The steering wheel must be mechanically connected to the front wheels.

11. The chassis must include both a main hoop and a front hoop.

1.3 Constraints

1. The maximum power drawn from the accumulator must not exceed 80 kW.

2. The maximum permitted voltage that may occur between any two points must not exceed 600 V DC.

3. A maximum of 12 kg is allowed in any accumulator container section.

4. Regenerating energy is allowed and unrestricted when the vehicle speed is more than 5 km/hr.

5. The brake pedal and system must withstand a minimum force of 2000 N

6. Wheels must be 203.2 mm (8.0 inches) or more in diameter.

7. The vehicle must be equipped with an operational suspension system with usable wheel travel of at least 50 mm, with a driver seated.

1.4 Criteria

1. **Performance**: Increase in handling, response, and tractive capability of the steering, suspension, and tires. Increase in acceleration and traction force of the vehicle.
2. **Serviceability**: Ease of repair, subsystems accessibility, parts interchangeability, low manufacturing complexity, and standardization of fasteners across the vehicle.
3. **Safety**: Visibility, cockpit protection, firewall, rollover protection, and scatter shields. Wiring is safely routed, color coded, and marked for function.
4. **Ergonomics**: Driver comfort, arm room, leg room, head restraint, ease of control, seat adjustability, and readability of essential instruments.
5. **Reliability**: Consistent and reliable braking system, drivetrain, and motor.
6. **Aerodynamics**: Drag reduction, lift reduction, noise elimination, and downforce gain.
7. **Cost**: Raw material selection, manufacturing process selection, and design optimizations for simpler solutions.
8. **Efficiency**: Lightweight design, increase in range, and improve in performance and structural integrity.

Chapter 2

Design Concepts

2.1 Chassis

2.1.1 Space frame

A structure constructed from an arrangement of round section steel tubing that are welded together. The frame is analogous to a truss style bridge with members constructed in a triangular pattern to support pure compression and tension. The structure is mainly composed of the front bulkhead, front hoop, and main hoop [25].

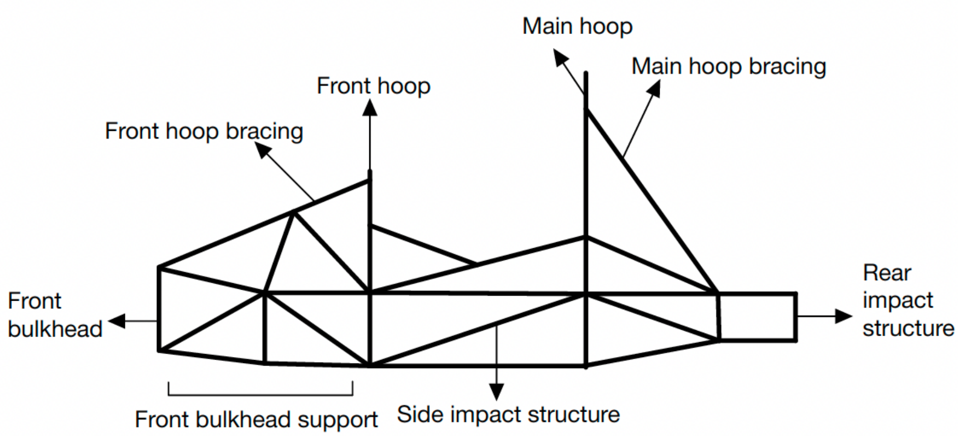


Figure 2.1: Side view of space frame chassis [1]

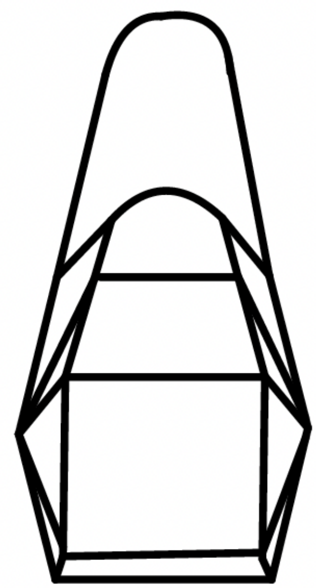


Figure 2.2: Front view of space frame chassis [1]

2.1.2 Carbon Fiber Monocoque

A one-piece structure consisting of two composite laminates housing an internal core structure. The external skins are constructed using carbon fiber reinforced polymers. The core is constructed using a honeycomb cell structure made from aluminum or aramid fibers [25].

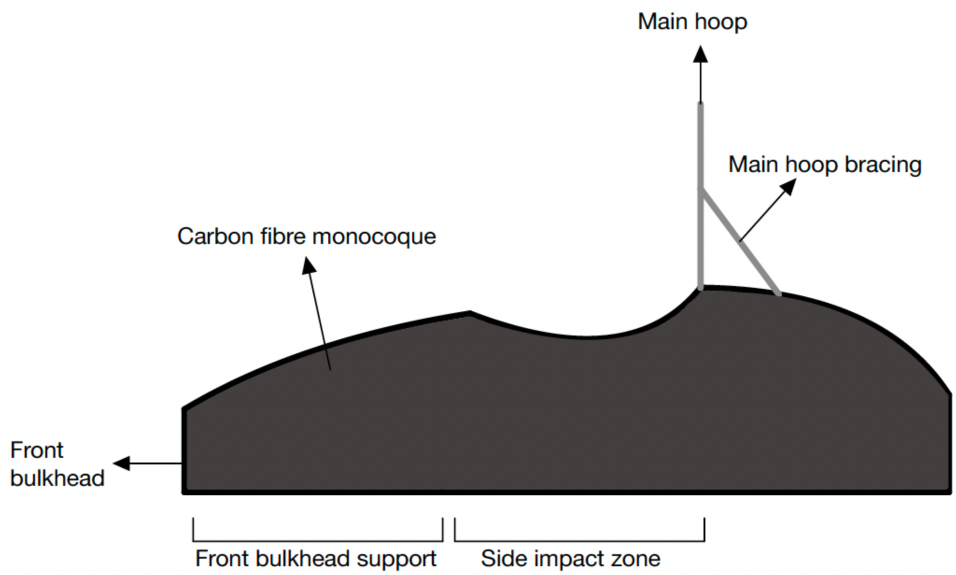


Figure 2.3: Side view of carbon fiber monocoque chassis [2]

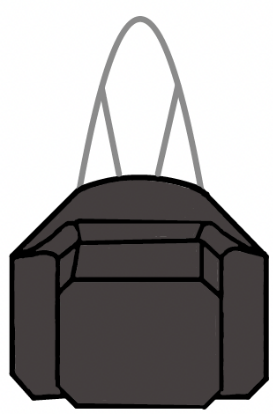


Figure 2.4: Front view of carbon fiber monocoque chassis [2]

2.1.3 Hybrid Monocoque

A combination of a front composite monocoque chassis and a rear space frame [26].

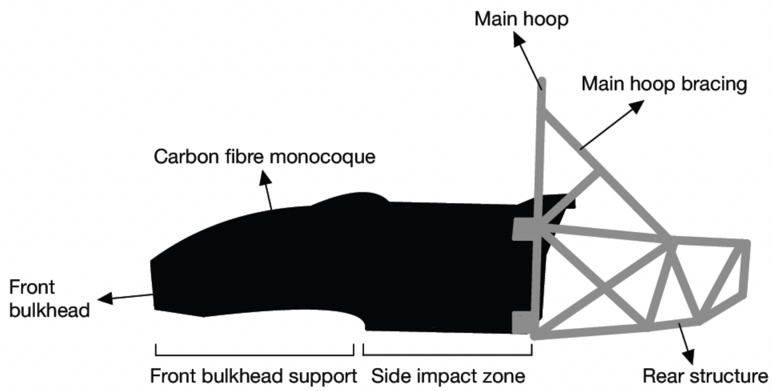


Figure 2.5: Side view of hybrid monocoque chassis [3]

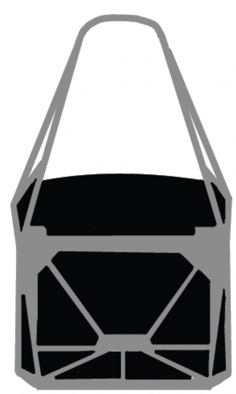


Figure 2.6: Rear view of hybrid monocoque chassis [3]

2.2 Motor and Drivetrain

2.2.1 Single Out-Wheel Motor and Chain Drive

The system involves the use of a single motor with a chain drive linked to a limited slip differential. The limited slip differential is connected to two half shafts on either side using tripod joints to transmit power to the wheels. The system is mounted on the rear of the vehicle using two mounts that hold the motor and the differential on the space frame. The mounts contain two bearings on either side of the differential and two bearings on either side of the motor.

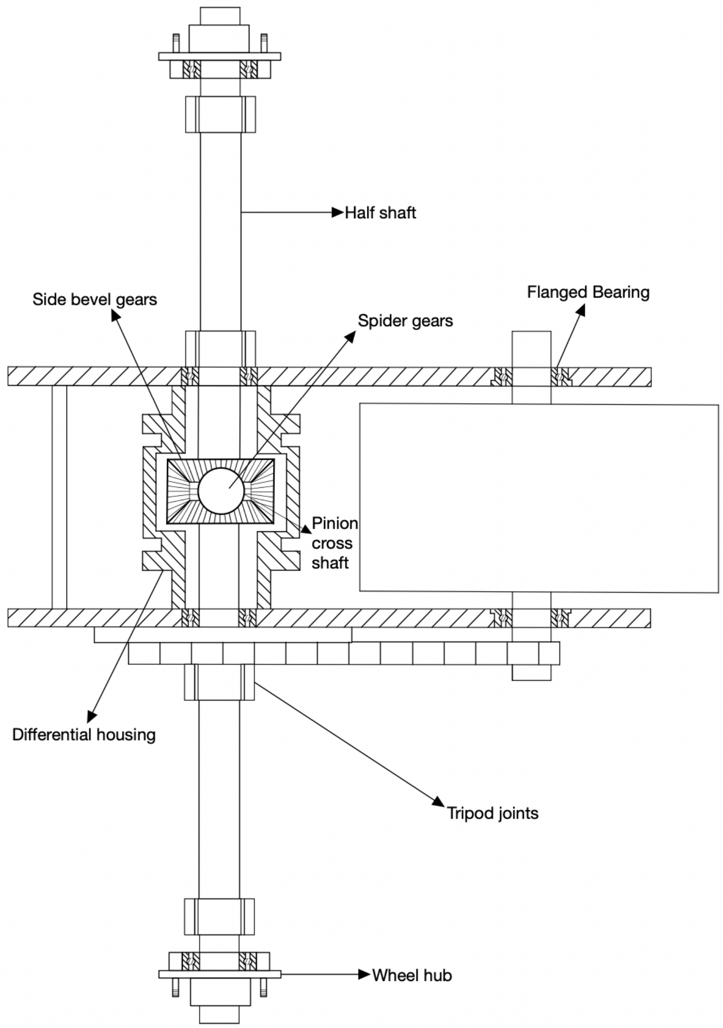


Figure 2.7: Top View of the Out-Wheel Motor with Chain and Sprocket Configuration [4] [5]

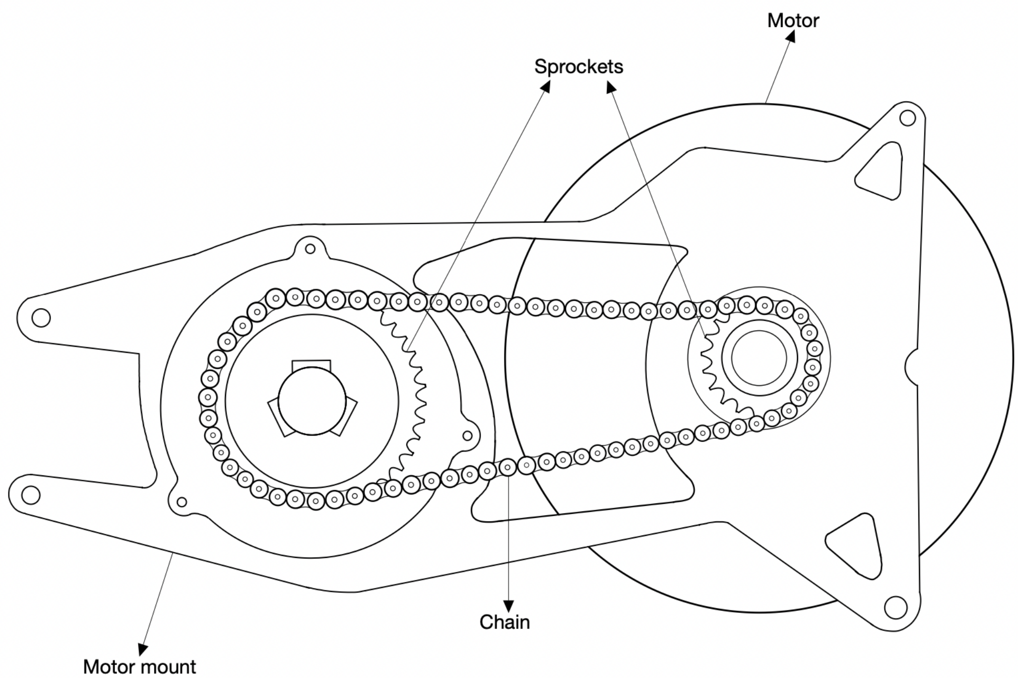


Figure 2.8: Front View of the Out-Wheel Motor with Chain and Sprocket Configuration [4]

2.2.2 Dual Out-Wheel Motors and Planetary Gearboxes

The system involves the use of two motors, each connected directly to a planetary gearbox. The planetary gearboxes transmit power to the two rear half shafts using tripod joints.

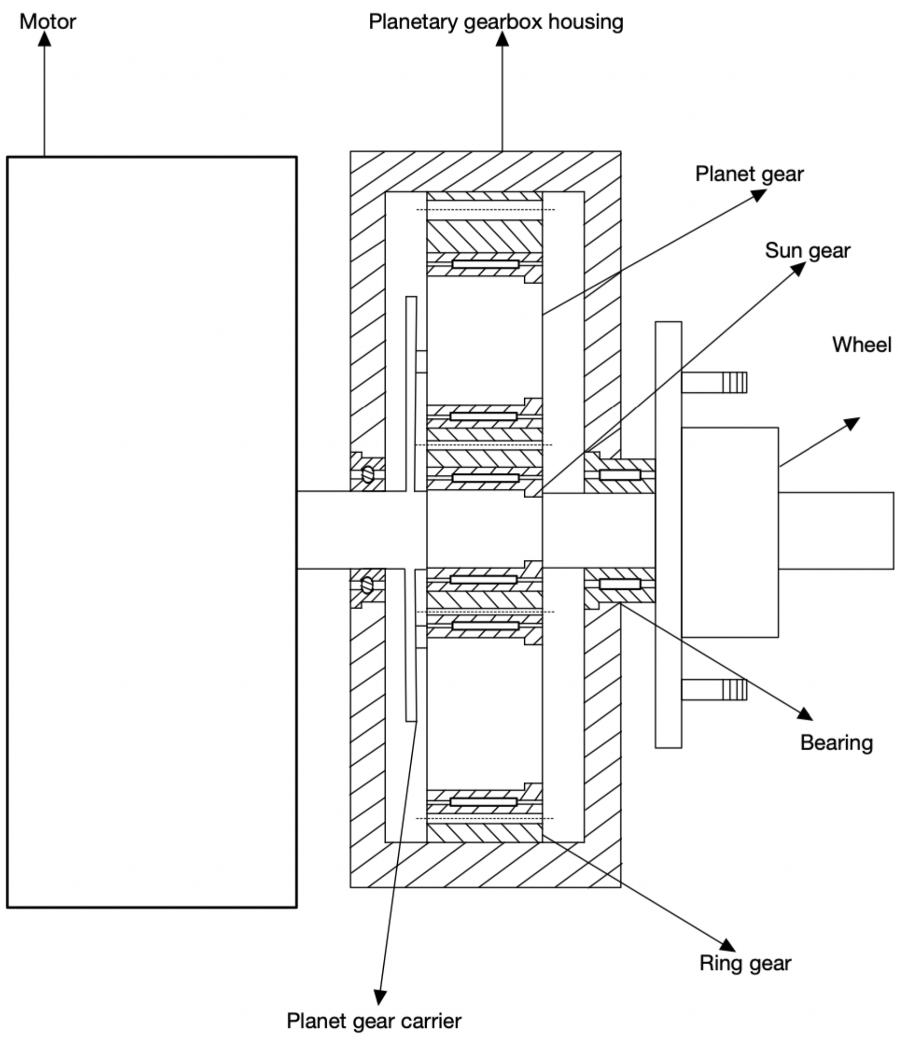


Figure 2.9: Side View of the Planetary Gearbox with a Motor [6]

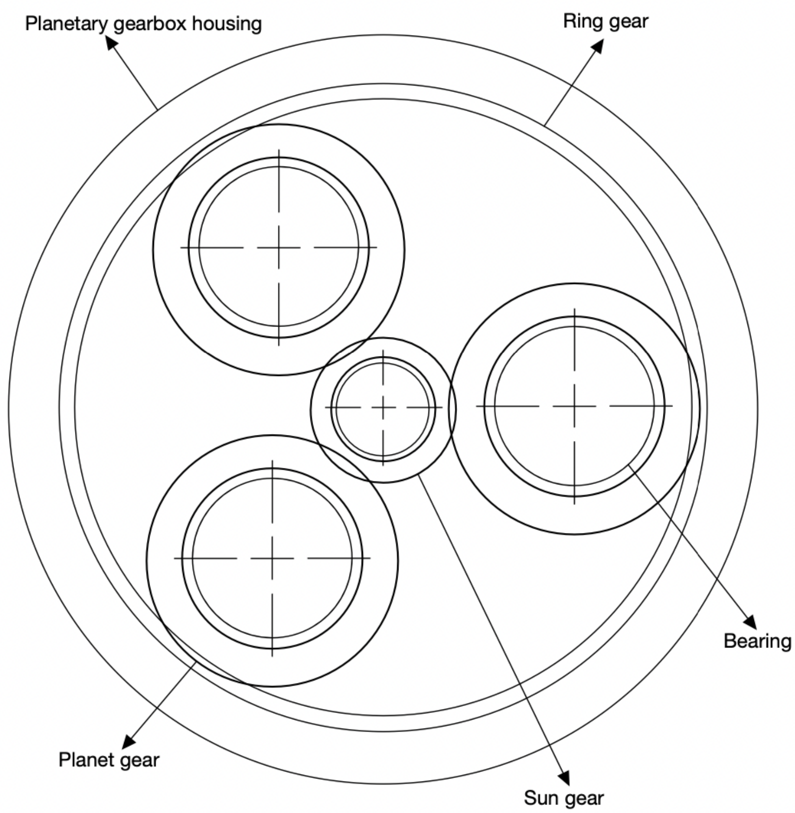


Figure 2.10: Front View of the Planetary Gearbox [7]

2.2.3 Four In-Wheel Motors and Planetary Gearboxes

The system involves the use of four motors, one at each wheel. Each motor is directly connected to a planetary gearbox that is attached to the wheel hub. The shaft extends from the planetary gearbox and transmits power to the wheels.

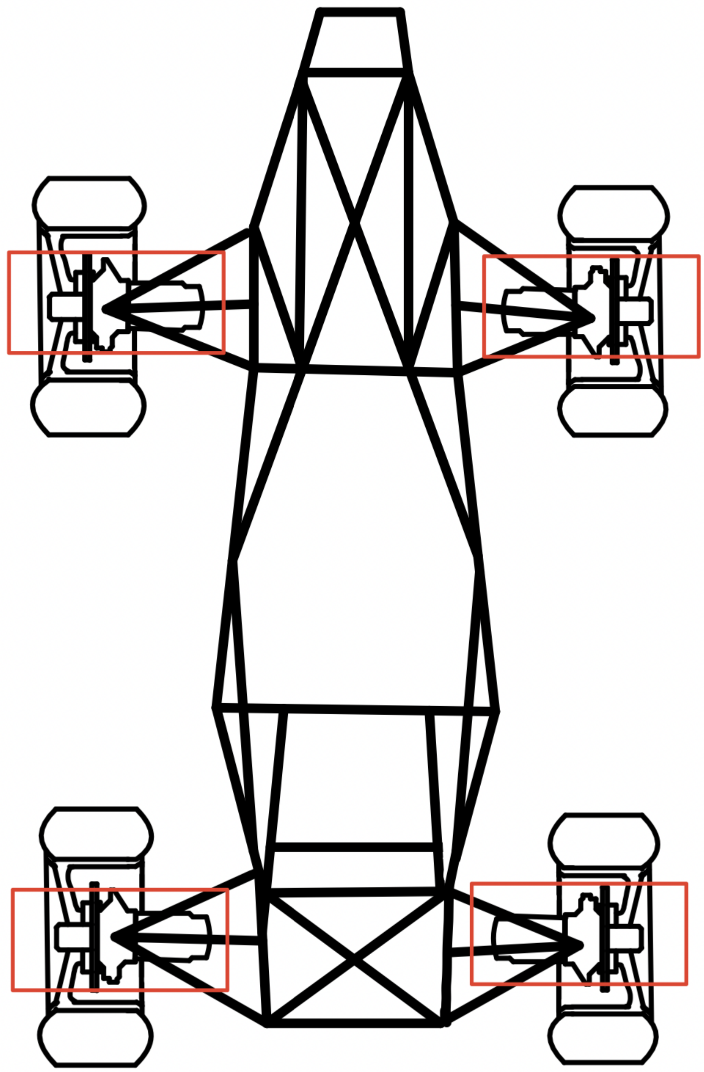


Figure 2.11: Locations of the Four In-Wheel Motors [8]

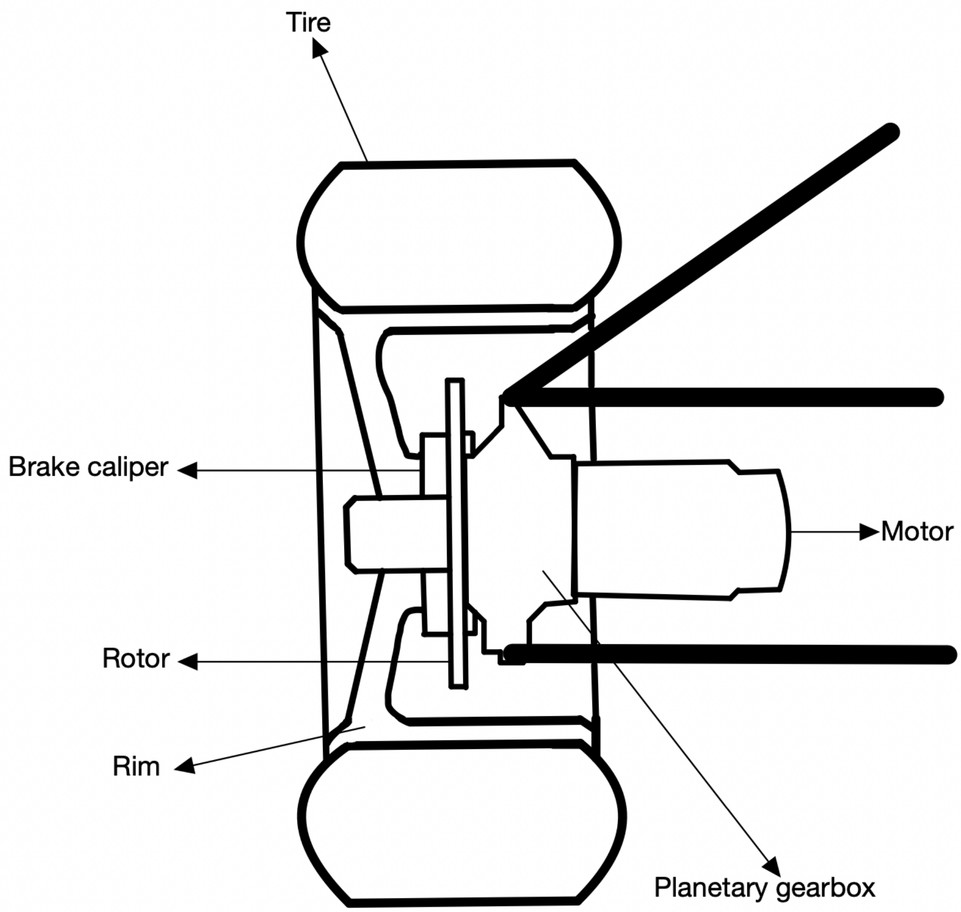


Figure 2.12: In-Wheel Motor Configuration [6]

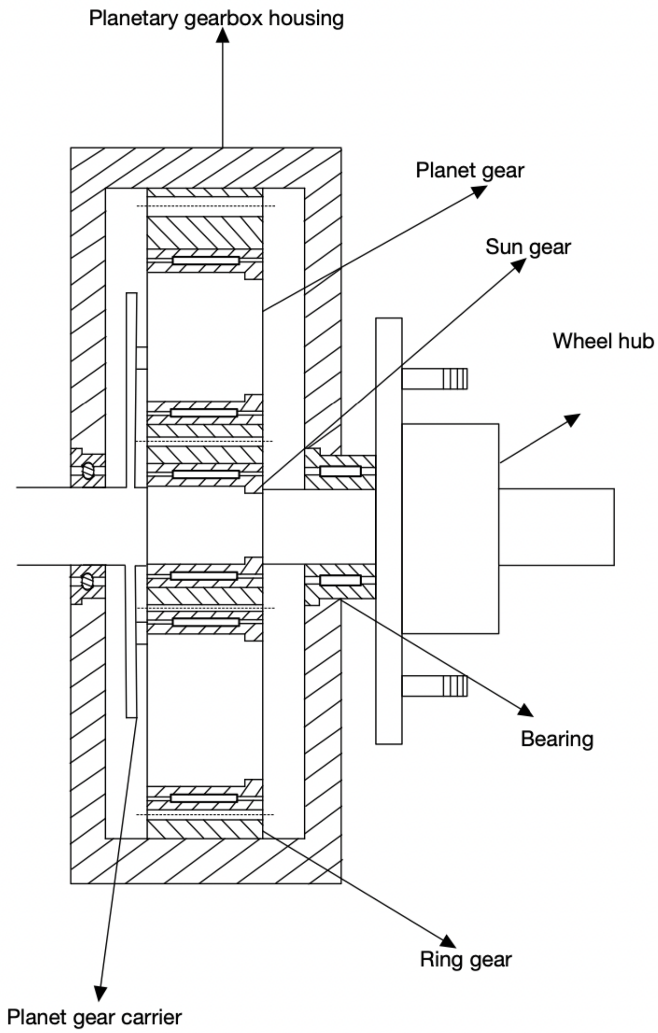


Figure 2.13: Planetary Gearbox Cross-section [6]

2.3 Steering

2.3.1 Recirculating Ball

Recirculating ball is a steering mechanism that contains worm gear inside a block. The steering wheel shaft feeds into the block and turns the threaded rod. Twisting the threaded rod causes the block and pitman arm to twist. The threads of the rod are filled with ball bearings to reduce friction and ease the motion of the steering [9].

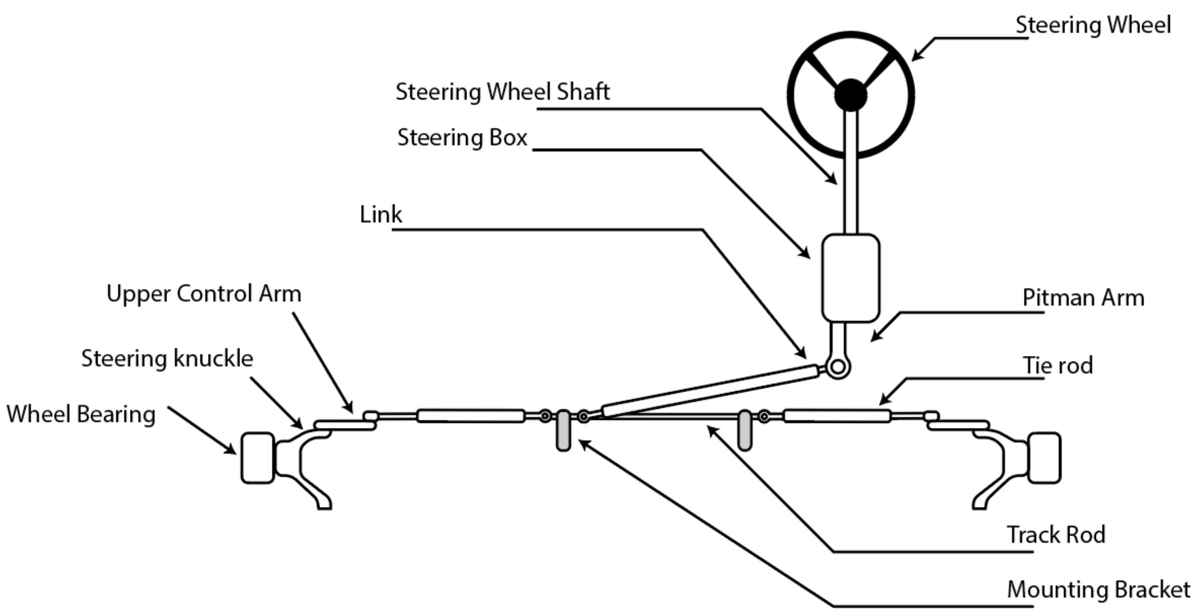


Figure 2.14: Front view of the recirculating steering system [9]

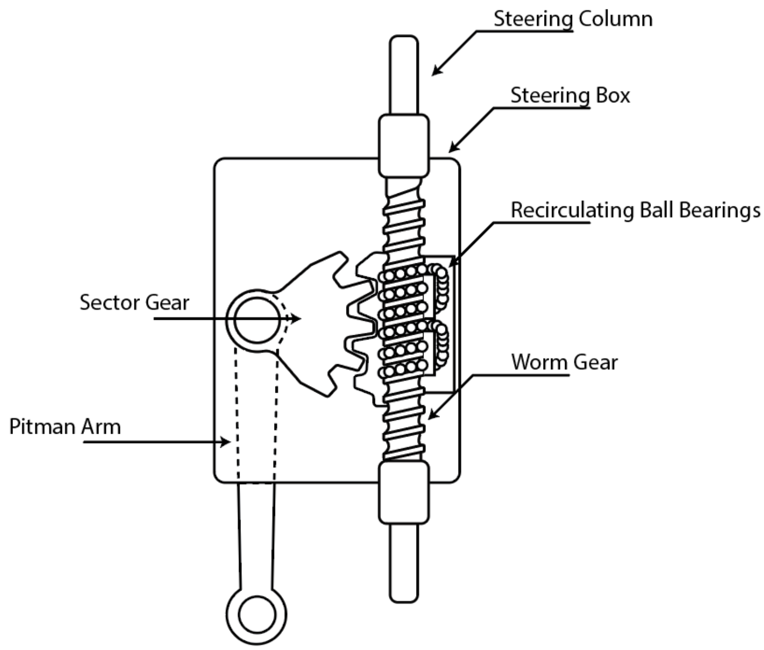


Figure 2.15: Close-up of the steering box [9]

2.3.2 Parallelogram Linkage

A parallelogram steering linkage contains two linkages that run parallel to each other and are equal in distance. The twist of the steering shaft transfers to the pitman arm, idler arm, and inner tie rods at each steering arm. All joints are constructed of small ball and socket joints [25].

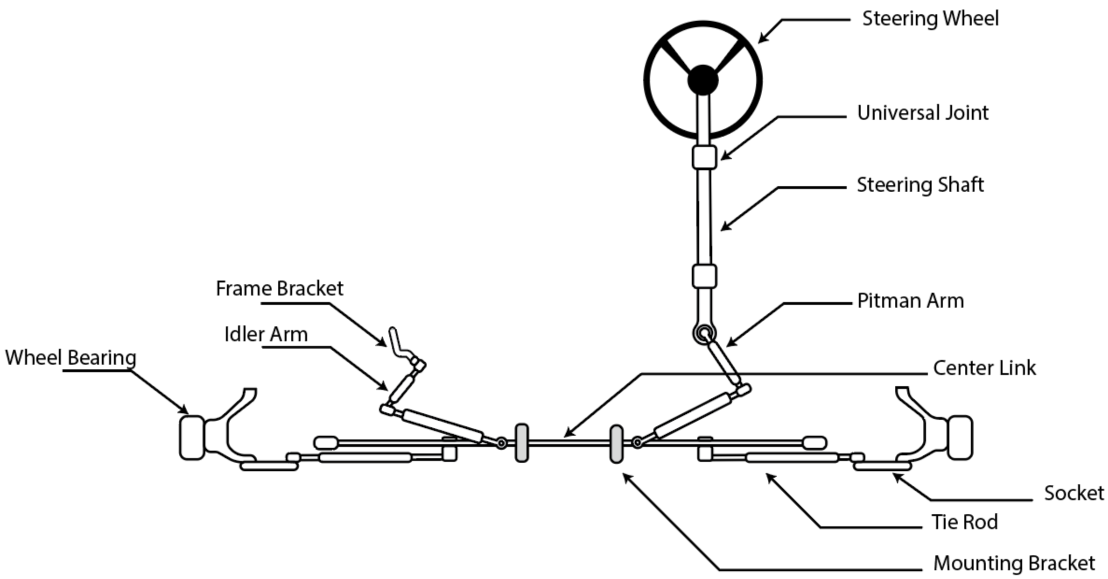


Figure 2.16: Front view of the parallelogram steering linkage system [10]

2.3.3 Rack & Pinion

The final concept uses a rack & pinion enclosed in a metal tube to control both tie rods. The rack & pinion is moved from the rotation of the steering shaft. Tie rods connect to the steering knuckle and control arm to move the wheel bearing [11].

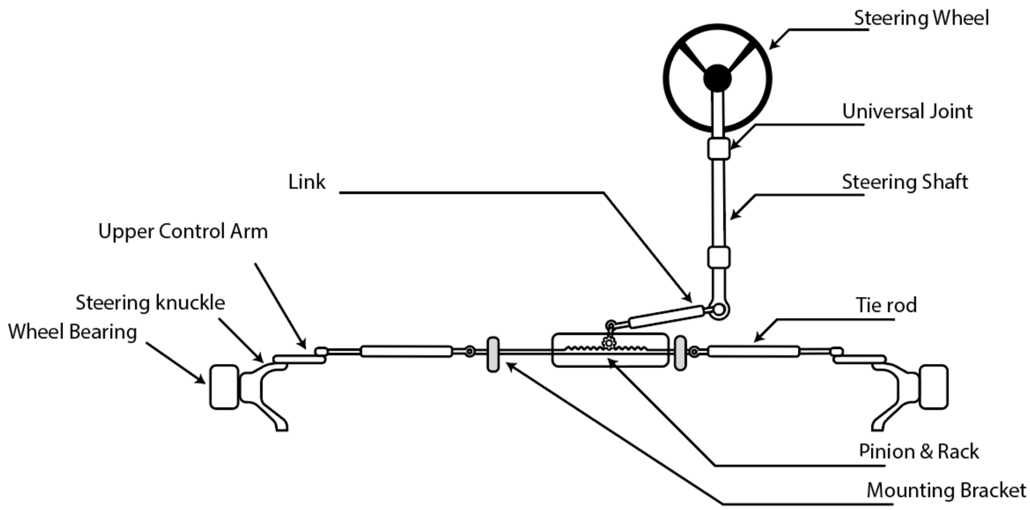


Figure 2.17: Front view of the rack & pinion steering system [11]

2.3.4 Mounting

Each steering system must be mounted onto the chassis of the vehicle. The top steering column will connect to the chassis with an enclosing chassis mount. The lower steering shafts will also have brackets connecting to the bottom portion of the chassis [12].

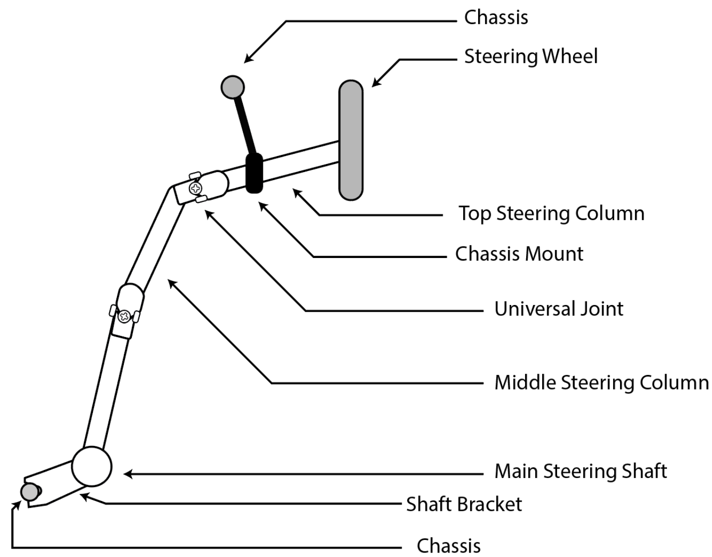


Figure 2.18: Side view of steering mechanism [12]

2.4 Brakes

2.4.1 Floating Calipers

Calipers are the assembly that house the brake pads and pistons. Calipers are mounted by a caliper bracket that is attached to the main wheel hub assembly.

Floating calipers contain one piston and two brake pads on each side of the rotor. To stop the car, the piston pushes against the brake pad against the rotor and slides to have the opposite brake pad make contact against the rotor [13].

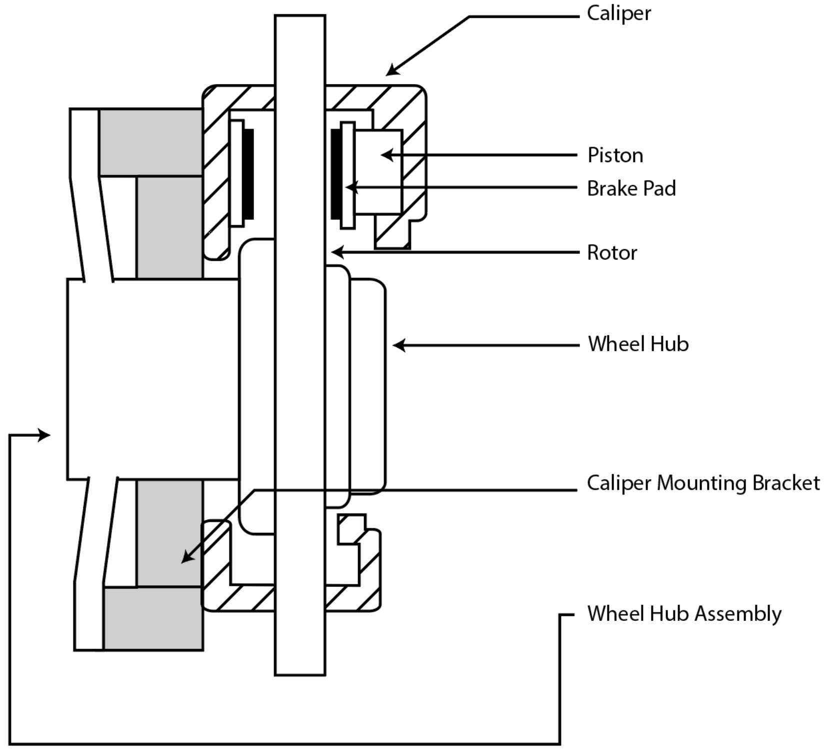


Figure 2.19: Side view of a brake rotor and a floating caliper [13]

2.4.2 Fixed Calipers

Fixed calipers are calipers that contain two pistons on each side of the rotor. Since both brake pads push to make contact against the brake rotor, the caliper maintains its position and does not need to slide [13].

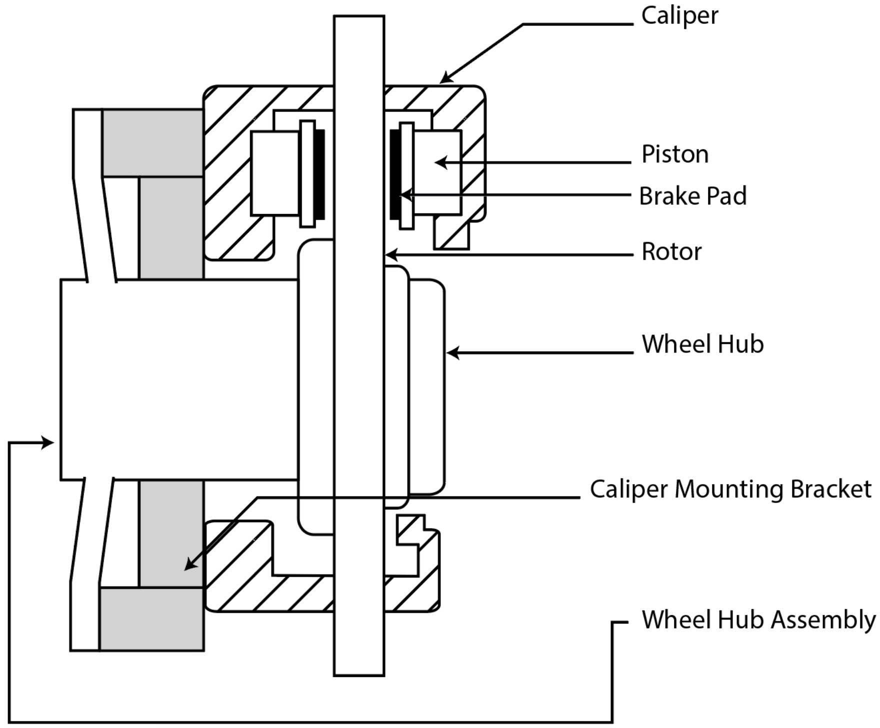


Figure 2.20: Side view of a brake rotor and a fixed caliper [13]

2.4.3 Drum Brakes

Drum Brakes are a type of brake configuration where a set of brake shoes and pads press outward against the rotating brake drum. The brake drum is mounted onto the wheel hub assembly with bolts. The interior brake shoe and spring are mounted on the back plate [14].

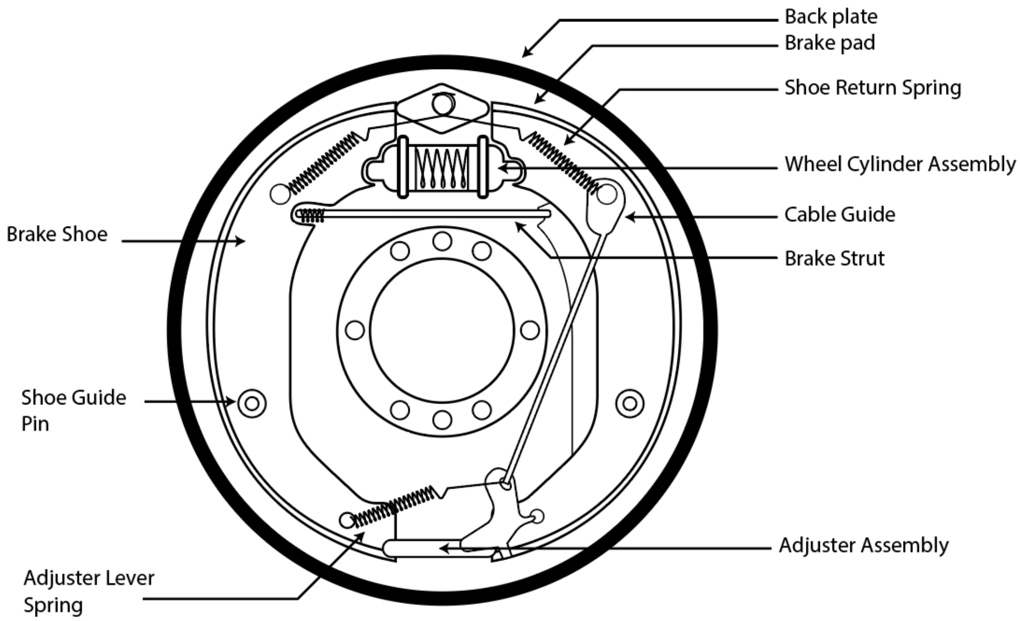


Figure 2.21: Front view of a drum brake [14]

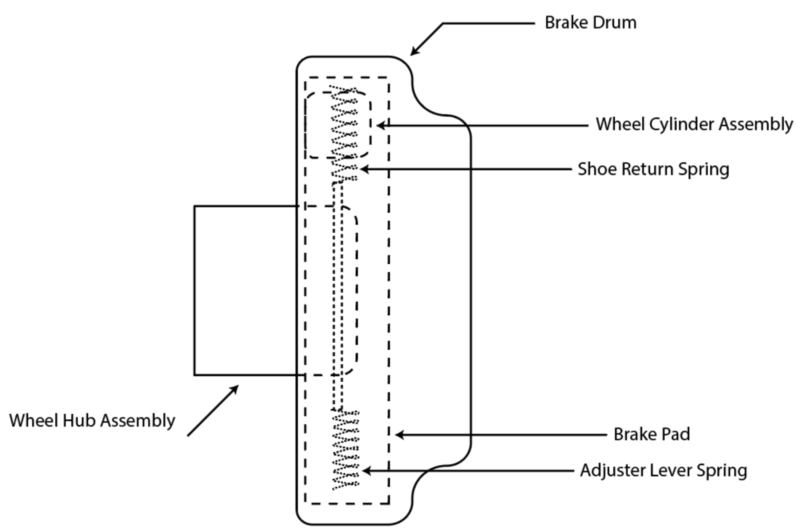


Figure 2.22: Side Assembly view of a drum brake [14]

2.5 Battery

2.5.1 Cylindrical Cells

Section walls are attached to the frame using either fasteners or epoxy resin. Circular cutouts are made to fit each cell within the section walls. Bus bars are attached to the section walls through grooves and can slide into these fittings. The bus bars are secured in location using fittings that restrict them from sliding out of the wall. Soldering wires are used to connect the positive and negative terminals of the battery cells to the bus bars to create a series connection for the entire section. Each section is connected via bus bars, either in series or in parallel. The bus bars connecting each section are attached using bolt connections.

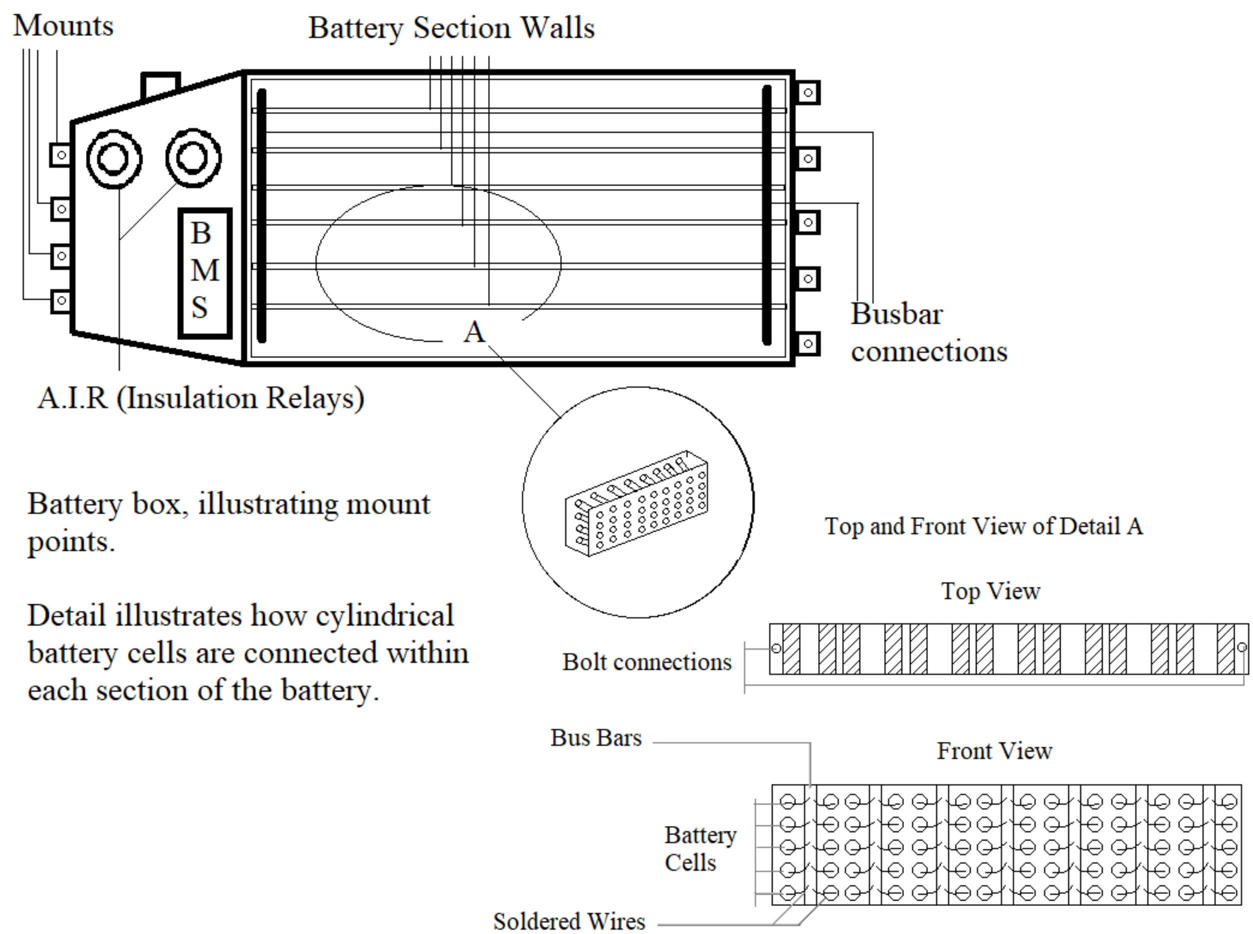


Figure 2.23: Top View of a Battery case with detail views for cylindrical cell sections [15] [16]

2.5.2 Pouch Cells

Pouch cells are attached together using an adhesive that creates spacing between pouches to account for any expansion and to improve the thermal properties of the battery. A clamp is used to hold the entire pouch assembly together in place inside the battery. Pouch Cells are connected using a rivet punch tool. Bus bars connect the terminals of each pouch cell together. The positive and negative terminals are attached at the end of each bus bar and can be connected in either series or parallel.

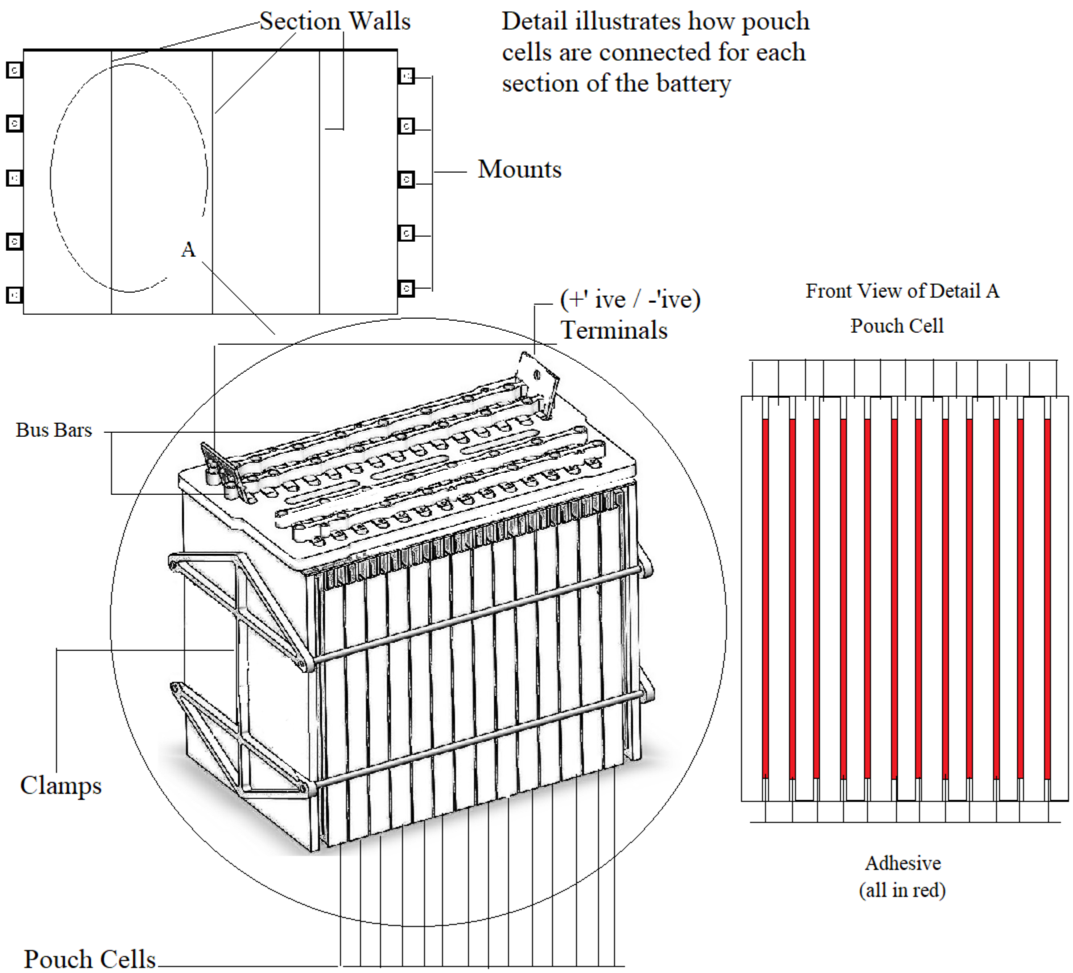


Figure 2.24: Top View of a Battery case with detail views for sections made up of pouch cells [17] [18] [19]

2.5.3 Prismatic Cells

Prismatic cells are connected together using the bus bar connections attached between the positive and negative terminals, and are secured between the section walls of the battery. To ensure a secure fit, a custom "n" shaped mount is placed onto the ends of each prismatic cell. To restrict their horizontal movement, a "u" shaped mount is placed at the walls of the battery.

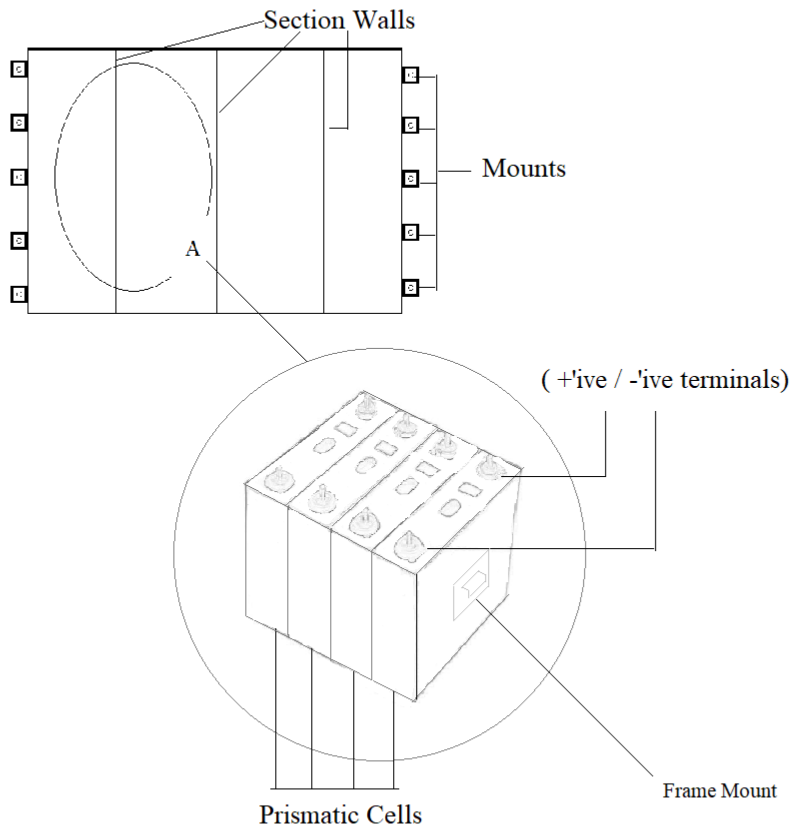


Figure 2.25: Top View of a Battery case with detail views for sections made up of prismatic cells [20]

2.6 Battery Mount

2.6.1 Direct Chassis Mounts Using Fasteners

The battery mount consists of a plate that is bolted directly to the battery case. It also consists of a top clamp that is bolted to the mount plate and tightly fitted to the chassis tubes.

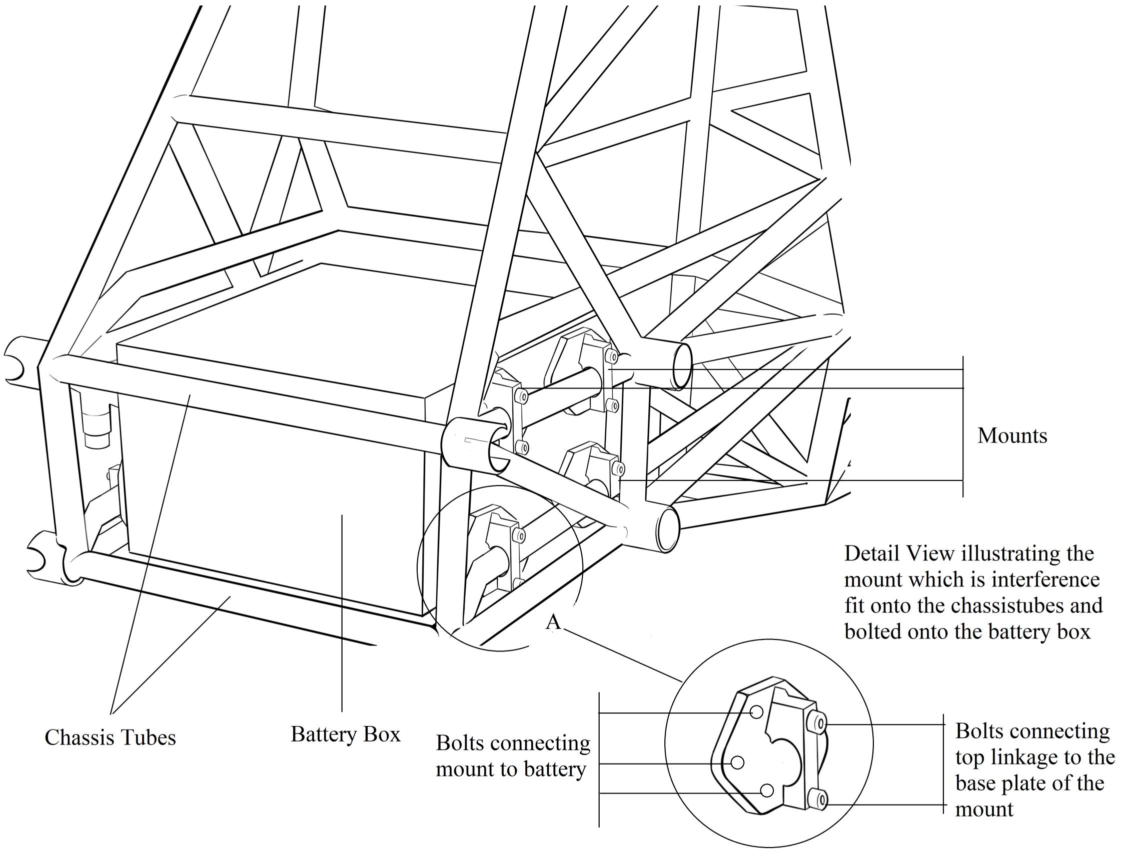


Figure 2.26: Isometric view of a battery directly mounted onto the chassis tubes [21]

2.6.2 Chassis Mounts through Welding

A plate is welded to the chassis frame and a mount is welded on to the battery case. These two pieces are then secured using a nut and bolt.

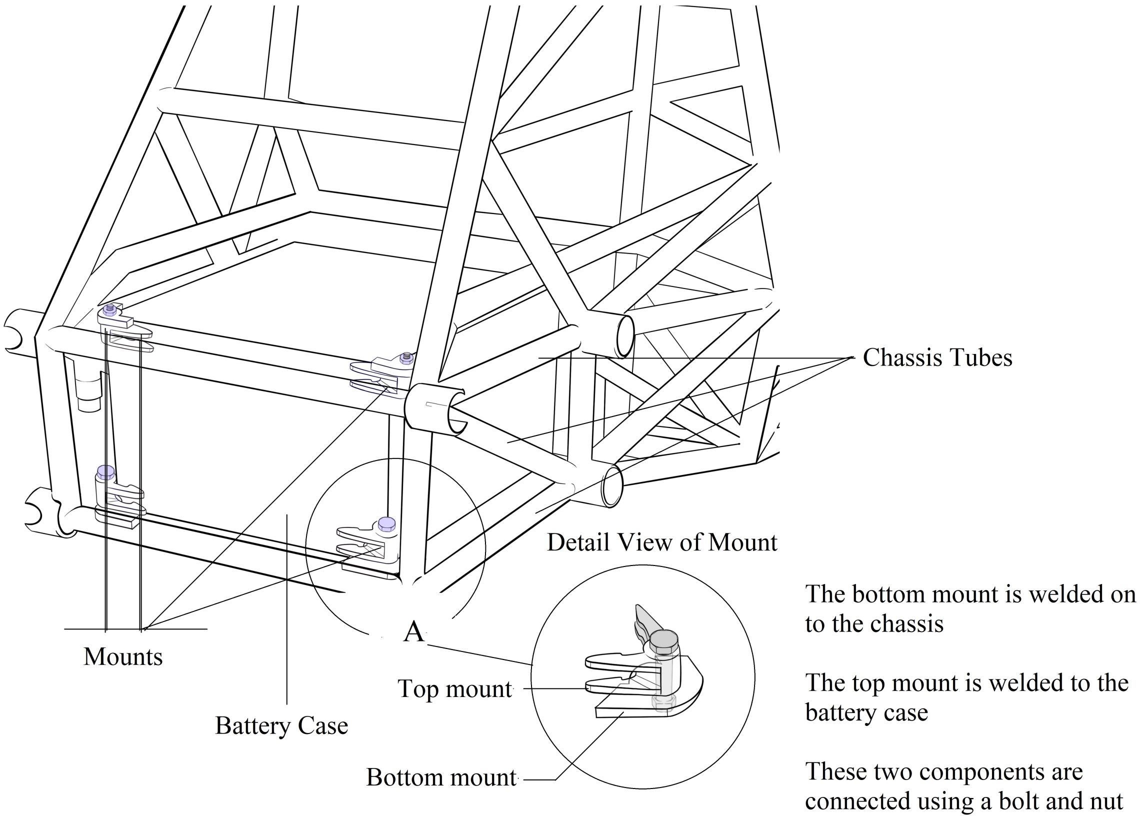


Figure 2.27: Isometric view of a battery indirectly mounted onto the chassis [16]

2.6.3 Sheet Metal Plate Mounts

A sheet metal plate is welded on to the floor of the chassis to create a solid base where the gusset mounts are bolted. The gusset mounts are then bolted to the battery case to secure it to the metal sheet plate.

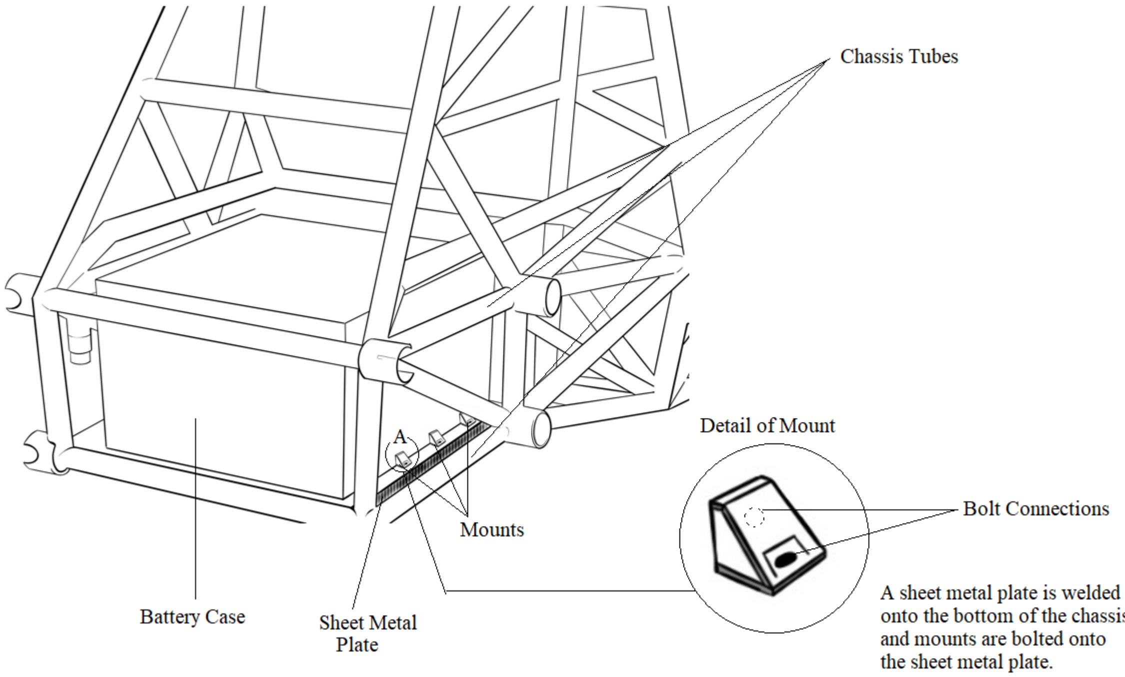


Figure 2.28: Isometric view of a battery mounted onto a sheet metal plate [18]

2.7 Suspension

2.7.1 Push Rod

A push rod suspension utilizes a push rod to connect the control arms to the spring and damper system [22]. The ends of the control arms have ball joints that are connected with a pin to their respective mounts on the wheel hub as well as the chassis. Similarly, the ends of the push rod also have ball joints that are connected with a pin to their respective mounts on the lower control arm and chassis [23]. The anti-roll bar is connected to the vehicle's chassis using load-bearing bushings. The ends of the anti-roll bar have linkages which allow for the mounting of a drop-link. These drop links are connected to the suspension system's rockers so that when the rocker pivots, some of the motion is transferred to the anti-roll bar alongside the coil-over shock absorbers [27].

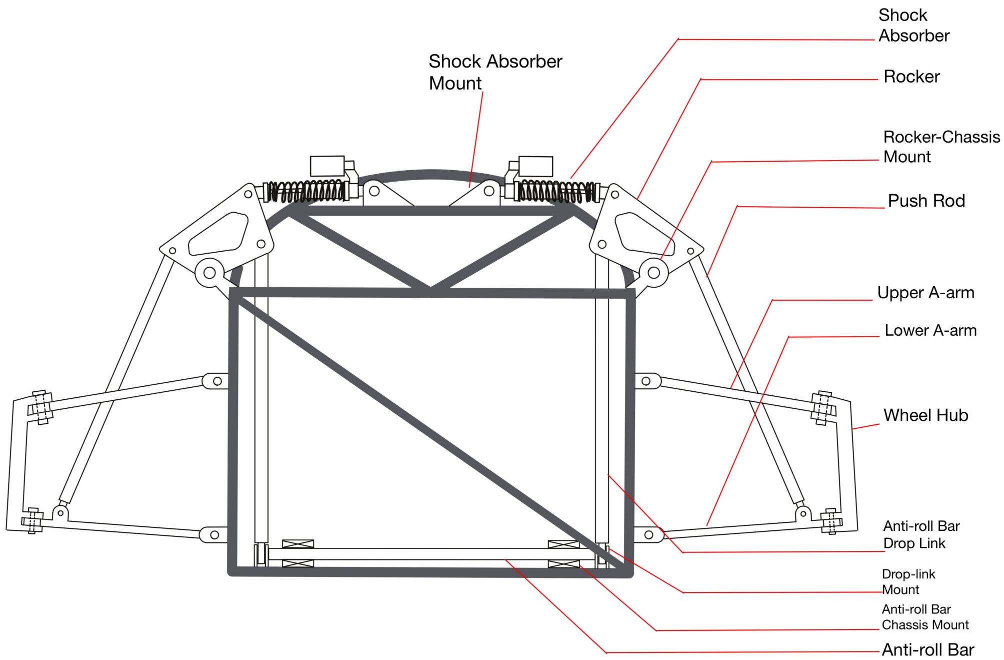


Figure 2.29: Front view of push rod suspension [22]

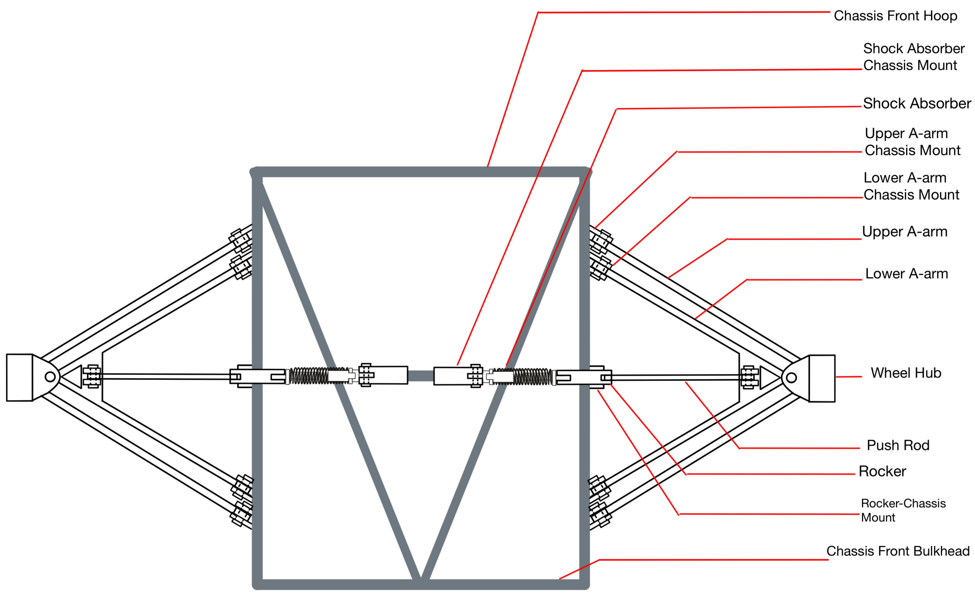


Figure 2.30: Top view of push rod suspension [22]

2.7.2 Pull Rod

A pull rod suspension behaves similarly to a push rod suspension. The pull rod linkage is mounted to the upper control arm. The upward wheel motion causes the pull rod linkage to pull on and rotate the rocker, thus extending the shock absorber instead of compressing it like in a push rod system [22].

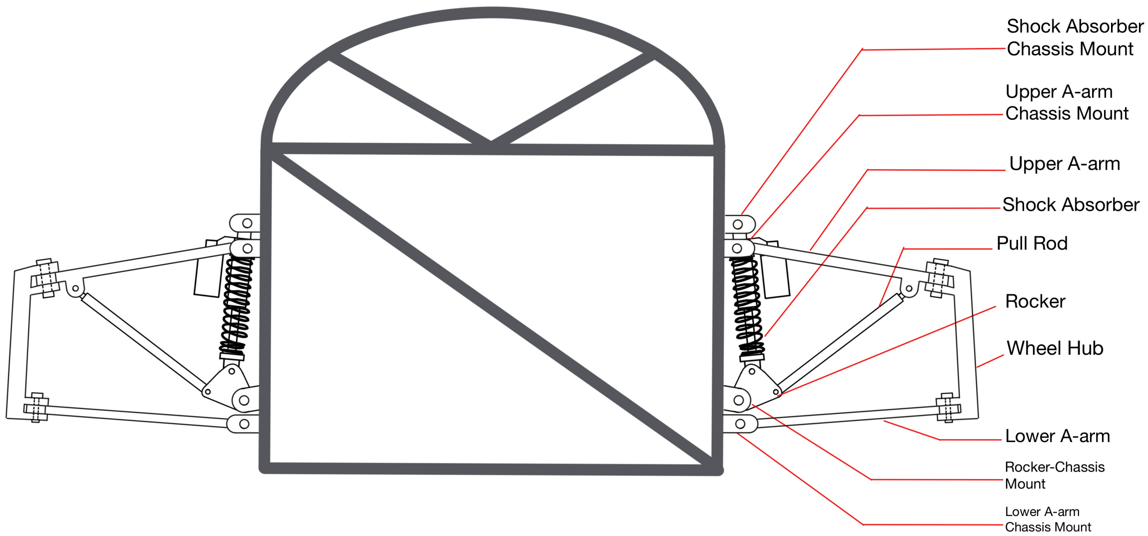


Figure 2.31: Front view of pull rod suspension [23]

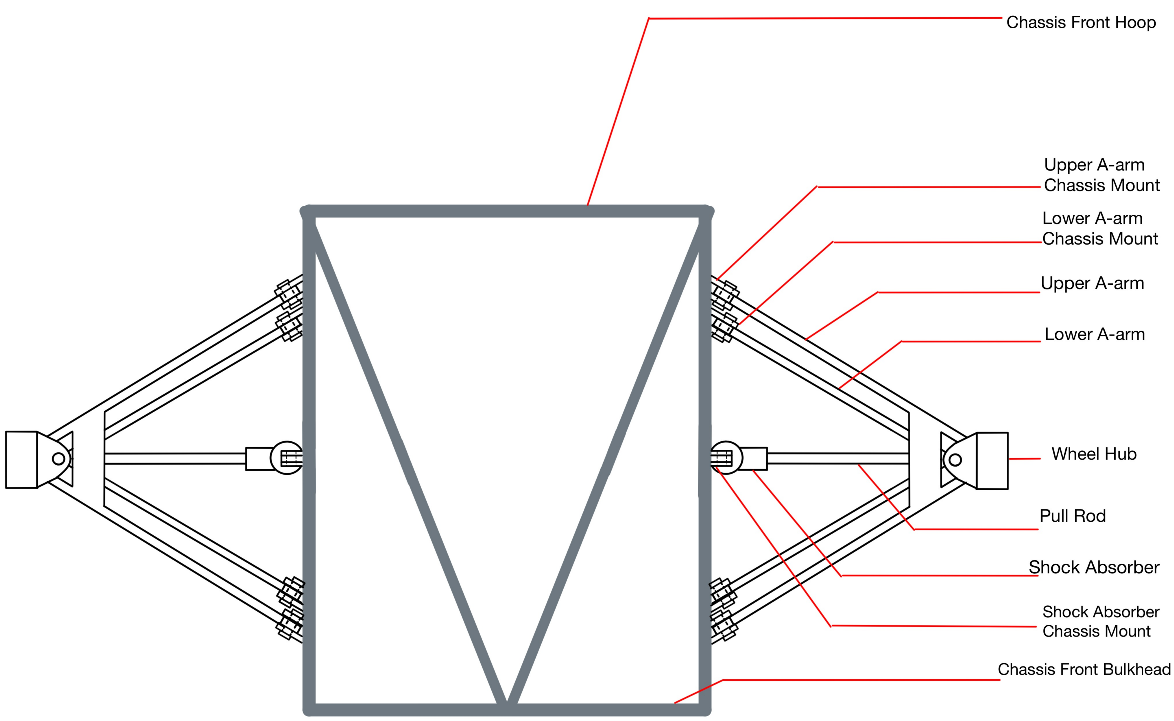


Figure 2.32: Top view of pull rod suspension [23]

2.7.3 Double-Wishbone

The double-wishbone suspension configuration features a shock absorber that is mounted directly from the lower control arm to the chassis. The loads on the control arms, mounts, and shock absorbers are greater in a double-wishbone setup and therefore, they have larger shock absorbers, stronger mounts and joints, as well as thicker control arms [28].

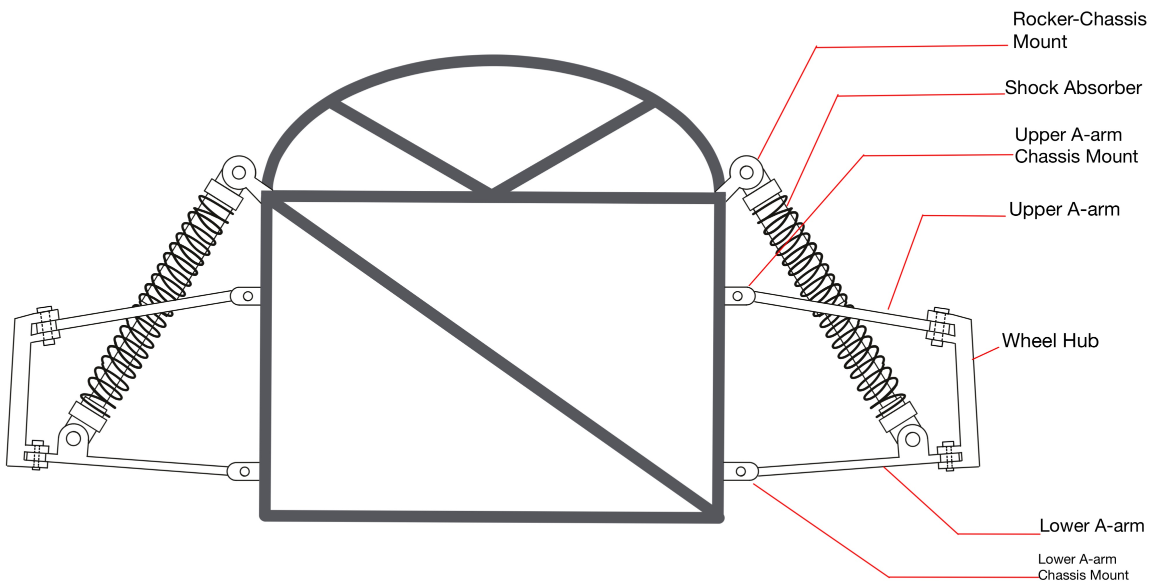


Figure 2.33: Front view of double-wishbone suspension [24]

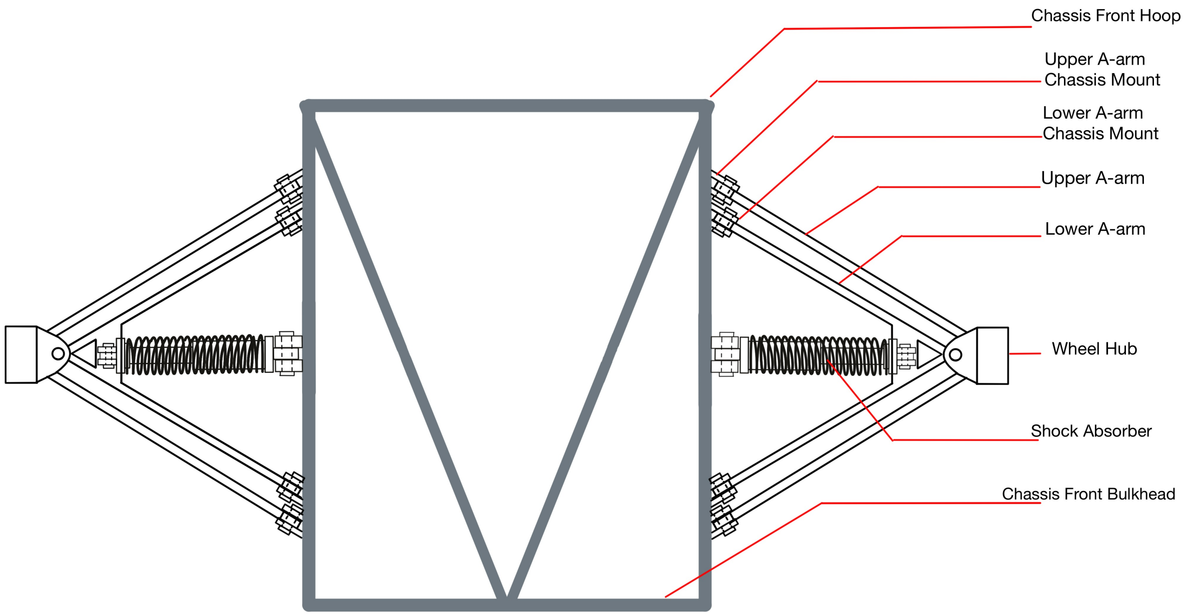


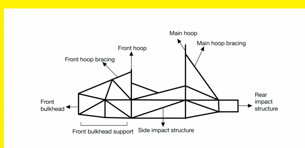
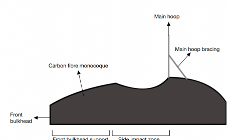
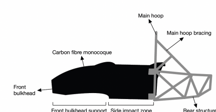
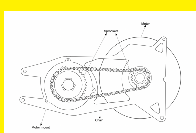
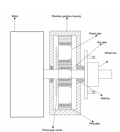
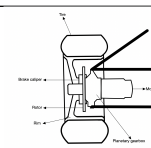
Figure 2.34: Top view of double-wishbone suspension [24]

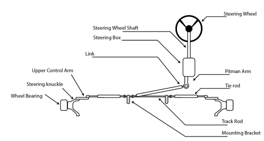
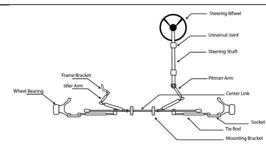
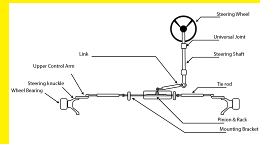
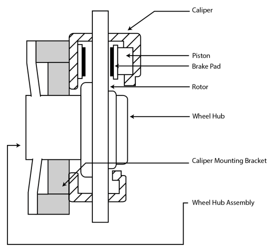
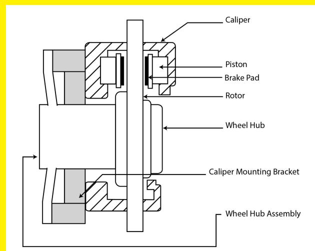
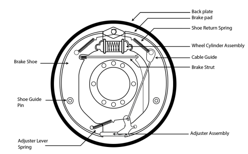
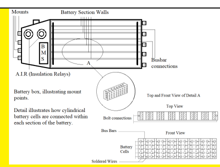
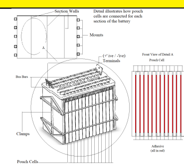
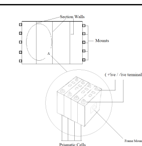
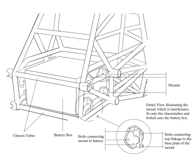
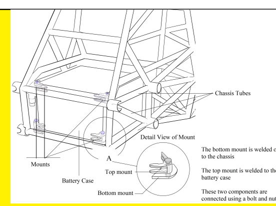
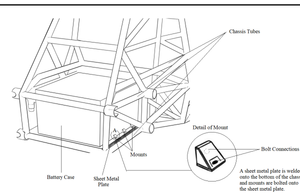
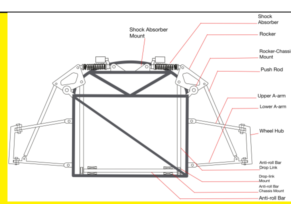
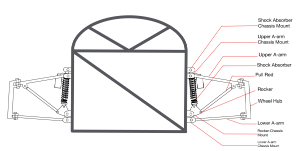
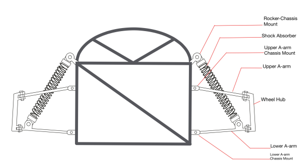
Chapter 3

Design Assessment

3.1 Summary Table of the Three Concepts

Table 3.1: Summary table of the three concepts

Component	**Concept 1**	**Concept 2**	**Concept 3**
Chassis	 Space Frame	 Carbon Fiber Monocoque	 Hybrid Monocoque
Motor & Drivetrain	 Single motor and chain drive	 Dual motors and planetary gearboxes	 Four In-Wheel Motors and Planetary Gearboxes

Steering	 Recirculating Ball	 Parallelogram Linkage	 Rack & Pinion
Brakes	 Floating Calipers	 Fixed Calipers	 Drum Brakes
Battery	 Cylindrical Cells	 Pouch Cells	 Prismatic Cells
Battery Mounts	 Chassis mounts using fasteners	 Chassis mounts through welding	 Sheet metal plate mounts
Suspension	 Push Suspension	 Pull Suspension	 Double Wishbone

3.2 Concept Costs

The cost analysis of each concept can be found in Appendix A, highlighting the components, labour, and material costs. All the estimated costs include labour. The space frame chassis configuration totalled $1,396.92. The single motor configuration totalled $7,418.91. The rack and pinion steering system totalled $2,786.16. The fixed caliper braking system totalled $4,377.00. The battery and mounting totalled $595.00. Lastly, the push rod suspension system totalled $4,360.00. The total cost of the vehicle was estimated to be around $20,844.

3.3 Decision Analysis

The decision criteria analysis tables for each concept are in Appendix B with appropriate criteria for each component weighted depending on each component's function.

3.3.1 Chassis

The space frame chassis tubular structure is selected for its rigidity and structural integrity. The space frame is also very affordable, easy to repair, and offers high accessibility to other components within the vehicle for maintenance purposes.

3.3.2 Motor and Drivetrain

The single out-wheel motor with chain and sprockets is selected for it affordability, lightweight design, and serviceability. Planetary gearboxes are relatively expensive with high maintenance costs and low accessibility. Also, additional motors increase the weight of the vehicle and negatively impact its performance.

3.3.3 Steering

The rack and pinion steering mechanism is selected for its high performance and agility. The parallelogram steering mechanism is outdated and serviceability would be difficult. The recirculating ball gearbox mechanism is very complex, making it less reliable and harder to maintain.

3.3.4 Brakes

Fixed calipers are selected for the braking system for their high reliability and safety due to their dual piston setup. The fixed calipers are the easiest to maintain compared to other braking mechanisms.

3.3.5 Battery

The cylindrical cell configuration is selected for its large weight to power ratio, reliability, and simplicity. This battery configuration is highly accessible for maintenance and service purposes compared to other cell configurations.

3.3.6 Battery Mount

The selected battery mount design is the chassis mounts through welding. It is a simple and reliable mounting option that provides the most options for battery placement on the chassis.

3.3.7 Suspension

The push rod suspension system is selected as it makes it easier to incorporate an anti-roll bar to benefit the overall performance of the suspension system. As shown in the decision analysis table, the push rod suspension received the highest total score.

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APPENDICES

Appendix A

Cost Analysis

In this analysis, it is assumed that all mechanical work such as assembling components and installations are going to be performed by a mechanic. The average licensed mechanic salary in Canada is $32 per hour.

A.1 Chassis

Table A.1: Spaceframe Chassis Cost Assessment

Item & Description	**Work Hours**	**Labour Cost**	**Material Cost**	**Total Cost**
Spaceframe - 4130 steel, round tube	16	$32.00	$537.18 [29]	$1,049.18
Anti-intrusion Plate	4	$32.00	$30.36 [29]	$158.36
Tabs	2	$32.00	$35.38 [29]	$99.38
Total				$1,306.92

Table A.2: Carbon Fiber Monocoque Cost Assessment

Item & Description	Work Hours	Labour Cost	Material Cost	Total Cost
4130 steel, round tube	4	$32.00	$365.98 [30]	$493.98
carbon monocoque	5	$32.00	$6,355.95 [30]	$6,515.95
Total				$7,009.93

Table A.3: Hybrid Monocoque Cost Assessment

Item & Description	Work Hours	Labour Cost	Material Cost	Total Cost
Tub material (layup) - HRH-10-1/8-3.0	2	$32.00	$1,754.24 [31]	$2,010.24
Tub material (layup) - End grain balsa	2	$32.00	$167.80 [31]	$231.80
4130 steel, round tube	8	$32.00	$329.24 [31]	$585.24
Total				$2,827.28

A.2 Motor And Powertrain

Table A.4: Cost Analysis for Out-Wheel Motor with Chain and Sprocket

Item & Description	**Work Hours**	**Labour Cost**	**Material Cost**	**Total Cost**
Motor	1	$32.00	$3,170.0 [32]	$3,202.02
Motor Mount	1	$32.00	$46.99 [33]	$78.99
Limited Slip Differential	3	$96.00	$2,525.20 [34]	$2,621.20
Chain and Sprocket Kit	1	$32.00	$249.99 [35]	$281.99
4 Bearings	N/A	N/A	$13.99 [36]	$13.99
Tripod Joint Housing (2 Units)	1	$32.00	$659.36 [37]	$691.36
Tripod Joint (2 Units)	N/A	N/A	$168.68 [38]	$168.68
Half Shaft Axle	1	$32.00	$328.68 [39]	$360.68
Total				$7,418.91

Table A.5: Total Subassembly Cost Two Motor Configuration

Item & Description	**Work Hours**	**Labour Cost**	**Material Cost**	**Total Cost**
Motor	1	$32.00	$3,170.02 [32]	$3,202.02
Planetary Gearboxes	2	$64.00	$594.38 [40]	$658.38
Motor Mount	1	$32.00	$46.99 [33]	$78.99
Tripod Joint Housing (2 units)	1	$32.00	$329.68 [37]	$361.68
Tripod Joint (2 units)	N/A	N/A	$168.68 [38]	$168.68
Total for two motors				$8,939.50

Table A.6: Cost Analysis for Four In-Wheel Motors

Item & Description	**Work Hours**	**Labour Cost**	**Material Cost**	**Total Cost**
Motor	1	$32.00	$2,028.71 [41]	$2,060.71
Planetary Gearboxes	1	$32.00	$594.38 [40]	$626.38
Total for four motors				$10,748.36

A.3 Steering

Table A.7: Cost Analysis of Rack and Pinion Steering System

Item & Description	Work Hours	Labour Cost	Material Cost	Total Cost
Rack, pinion, and Housing	1	$32.00	$1,469.46 [42]	$1501.46
Upper Control Arm (2 units)	1	$32.00	$196.62 [43]	$228.62
Steering Knuckle and Wheel (2 units)	1	$32.00	$333.78 [44]	$365.78
Steering Wheel	1	$32.00	$150.50 [45]	$182.5
Universal Joint	1	$32.00	$88.79 [46]	$120.79
Steering Shaft	1	$32.00	$169.57 [47]	$201.57
Tie Rod 2	1	$32.00	$58.06 [48]	$90.06
Mounting Bracket 2	1	$32.00	$63.38 [49]	$95.38
Total				$2786.16

Table A.8: Cost Analysis of Recirculating Gearbox Steering System

Item & Description	**Work Hours**	**Labour Cost**	**Material Cost**	**Total Cost**
Recirculating Gearbox	1	$32.00	$358.61 [50]	$390.61
Upper Control Arm (2 units)	1	$32.00	$196.62 [43]	$228.62
Steering Knuckle and Wheel (2 units)	1	$32.00	$333.78 [44]	$365.78
Pitman Arm	1	$32.00	$64.73 [51]	$96.73
Steering Wheel	1	$32.00	$150.50 [45]	$182.5
Universal Joint	1	$32.00	$88.79 [46]	$120.79
Steering Shaft	1	$32.00	$169.57 [47]	$201.57
Tie Rod 2	N/A	N/A	$58.06 [48]	$90.06
Mounting Bracket	N/A	N/A	$63.38 [49]	$63.38
Total				$1740.04

Table A.9: Cost Analysis of Parallelogram Steering System

Item & Description	**Work Hours**	**Labour Cost**	**Material Cost**	**Total Cost**
Idle Arm	1	$32.00	$119.86 [52]	$151.86
Upper Control Arm (2 units)	1	$32.00	$196.62 [43]	$228.62
Steering Knuckle and Wheel (2 units)	1	$32.00	$333.78 [44]	$365.78
Pitman Arm	1	$32.00	$64.73 [51]	$96.73
Steering Wheel	1	$32.00	$150.50 [45]	$182.5
Universal Joint	1	$32.00	$88.79 [46]	$120.79
Steering Shaft	1	$32.00	$169.57 [47]	$201.57
Tie Rod	2	$32.00	$58.06 [48]	$90.06
Mounting Bracket	N/A	N/A	$63.38 [49]	$63.38
Total				$1501.29

A.4 Brakes

Table A.10: Cost Analysis for Fixed Caliper

Item & Description	Work Hours	Labour Cost	Material Cost	Total Cost
Caliper	1	$32.00	$2,504.00 [53]	$2,536.00
Brake Pads	1	$32.00	$375.00 [54]	$407.00
Mounting Bracket	1	$32.00	$50.00 [55]	$82.00
Rotor	1	$32.00	$1,320.00 [56]	$1,352.00
Total				$4,377.00

Table A.11: Cost Analysis for Floating Caliper

Item & Description	Work Hours	Labour Cost	Material Cost	Total Cost
Caliper	1	$32.00	$404.00 [57]	$436.00
Brake Pads	1	$32.00	$375.00 [54]	$407.00
Mounting Bracket	1	$32.00	$50.00 [55]	$82.00
Rotor	1	$32.00	$1,320.00 [56]	$1,352.00
Total				$2,277.00

Table A.12: Cost Analysis for Drum Brakes

Item & Description	**Work Hours**	**Labour Cost**	**Material Cost**	**Total Cost**
Brake Drums	1	$32.00	$240.00 [14]	$272.00
Brake Pads	1	$32.00	$100.00 [14]	$132.00
Springs	1	$32.00	$20.00 [14]	$52.00
Total				$456.00

A.5 Battery

Table A.13: Cost Analysis of Cylindrical Cell Configuration

Item and Description	**Work Hours**	**Labour**	**Material Cost**	**Total Cost**
Section Walls Epoxy Resin FR04	2	$32.00	$13.00 [58]	$77.00
Battery Case Aluminum Sheet Metal	3	$32.00	$379.00 [59]	$443.00
Total Cost				$520.00

Table A.14: Cost Analysis of Pouch Cell Configuration

Item and Description	Work Hours	Labour	Labour	Labour
Section Walls Epoxy Resin FR04	1.5	$32.00	$13.00 [58]	$61.00
Pouch Cell Clamp Aluminum Sheet Metal 6061	2	$32.00	$63.00 [59]	$127.00
Battery Case Aluminum Sheet Metal 6061	2	$32.00	$279.00 [59]	$343.00
Total Cost				$531.00

Table A.15: Cost Analysis of Prismatic Cell Configuration

Item and Description	Work Hours	Labour	Material Cost	Total Cost
Section Walls Aluminum Sheet Metal 6061	1.5	$32.00	$71.00 [59]	$119.00
Electrical and fire retardant insulation Nomex	0.5	$32.00	$155.00 [60]	$171.00
Battery Case Aluminum Sheet Metal 6061	2	$32.00	$430.00 [59]	$494.00
Total Cost				$784.00

A.6 Battery Mount

Table A.16: Fastener Chassis Mount Cost Assessment

Item and Description	Work Hours	Labour	Material Cost	Total Cost
Mounting Plate Aluminum 6061	1	$120.00	$21.00 [59]	$141.00
Bracket Connecting Bar to Mounting Plate Aluminum 6061	0.5	$32.00	$15 [59]	$31.00
Total Cost				$61.00

Table A.17: Welded Chassis Mount Cost Assessment

Item and Description	Work Hours	Labour	Material Cost	Total Cost
Bottom Plate to be machined and welded onto chassis Aluminum 6061	1	$32.00	$13.00 [59]	$45.00
Bracket welded onto Battery box and connected to bottom plate Aluminum 6061	0.5	$32.00	$14.00 [59]	$30.00
Total Cost				$75.00

Table A.18: Sheet Metal Mount Cost Assessment

Item and Description	Work Hours	Labour	Material Cost	Total Cost
Bottom Aluminum Sheet Plate to be welded to the Floor of the Frame	1	$32.00	$93.00 [59]	$125.00
Gusset Mounts to be bolted down to sheet plate Aluminum 6061	0.5	$32.00	$16.00 [59]	$32.00
Total Cost				$157.00

A.7 Suspension

Table A.19: Cost Analysis of Push Rod Suspension

Item & Description	Work Hours	Labour Cost	Material Cost	Total Cost
Push Rod Linkages	2	$240.00	$75.00 [61]	$315.00
Control Arms	3	$360.00	$150.00 [61]	$510.00
Mounts	3	$360.00	$200.00 [62]	$560.00
Rockers	4	$480.00	$350.00 [63]	$830.00
Shock Absorbers	4	$480.00	$350.00 [64]	$830.00
Anti-roll bars and linkages	1	$120.00	$75.00 [61]	$195.00
Bearings, bushings, ball joints, pins	1	$120.00	$1,000.00 [61]	$1,120.00
Total				$4,360.00

Table A.20: Cost Analysis of Pull Rod Suspension

Item & Description	**Work Hours**	**Labour Cost**	**Material Cost**	**Total Cost**
Pull Rod Linkages	2	$120.00	$75.00 [61]	$195.00
Control Arms	3	$360.00	$150.00 [61]	$510.00
Mounts	4	$480.00	$175.00 [61]	$655.00
Rockers	4	$480.00	$350.00 [63]	$830.00
Shock Absorbs	1	$32.00	$350.00 [64]	$382.00
Bearings, bushings, ball joints, pins	1	$32.00	$600.00 [61]	$632.00
Total				$3,204.00

Table A.21: Cost Analysis of Double-Wishbone Rod Suspension

Item & Description	**Work Hours**	**Labour Cost**	**Material Cost**	**Total Cost**
Control Arms	3	$360.00	$175.00 [61]	$535.00
Mounts	2	$240.00	$200.00 [61]	$440.00
Shock Absorbers	1	$32.00	$1,240.00 [65]	$1,272.00
Bearings, bushings, ball joints, pins	1	$32.00	$500.00 [61]	$532.00
Total				$2,779.00

Appendix B

Decision Analysis

B.1 Chassis

Table B.1: Chassis Configuration Criteria Analysis

Criteria	**Weight**	**Chassis Configuration**					
		Space Frame		**Carbon Fiber Monocoque**		**Hybrid Monocoque**	
		S1	S1*W	S2	S2*W	S3	S3*W
Cost	35	3	105	1	35	2	70
Weight	20	1	20	3	60	2	40
Maintenance	10	3	30	1	10	2	20
Safety	20	3	60	2	40	1	20
Aesthetics	15	1	15	3	45	2	30
Total	100		230		190		180

B.2 Motor and Powertrain

Table B.2: Battery Mount Configuration Criteria Analysis

Criteria	Weight	Motor and Powertrain Configuration					
		Out-wheel motor with chain and sprockets		Two in-wheel motors with two planetary gear-boxes		Four in-wheel motor with two planetary gear-boxes	
		S1	S1*W	S2	S2*W	S3	S3*W
Cost	25	3	75	2	50	1	25
Reliability	15	3	45	2	30	1	15
Weight	15	3	45	2	30	1	15
Maintenance	15	3	45	2	30	1	15
Performance	10	1	10	2	20	3	30
Power Consumption	10	3	30	2	20	1	10
Noise	5	1	5	3	15	2	10
Simplicity	5	3	15	2	10	1	5
Total	100		270		205		125

B.3 Steering

Table B.3: Steering System Criteria Analysis

Criteria	Weight	Steering Configuration					
		Rack and Pinion		Recirculating gearbox		Parallelogram	
		S1	S1*W	S2	S2*W	S3	S3*W
Cost	15	1	15	2	30	3	45
Simplicity	15	3	45	1	15	2	30
Reliability	20	3	60	2	40	1	20
Maintenance	20	3	60	1	20	2	40
Weight	15	3	45	1	15	2	30
Performance	15	3	45	2	30	1	15
Total	100		270		150		180

B.4 Brakes

Table B.4: Brake Configuration Criteria Analysis

Criteria	**Weight**	**Brakes Configuration**					
		Fixed Caliper		**Floating Caliper**		**Drum Brakes**	
		S1	S1*W	S2	S2*W	S3	S3*W
Cost	20	1	20	2	40	3	60
Simplicity	15	1	15	2	30	3	45
Reliability	30	3	90	1	30	2	60
Maintenance	10	3	30	2	20	1	10
Weight	5	2	10	3	15	1	5
Safety	20	3	60	1	20	2	40
Total	100		225		155		220

B.5 Battery

Table B.5: Battery Cell Configuration Criteria Analysis

Criteria	Weight	Cell Configuration					
		Cylindrical		Pouch		Prismatic	
		S1	S1*W	S2	S2*W	S3	S3*W
Cost	20	3	60	2	40	1	20
Size	15	2	30	3	45	1	15
Weight	15	3	45	2	30	1	15
Safety	15	3	45	1	15	2	30
Reliability	15	3	45	2	30	1	15
Simplicity	10	3	30	1	10	2	20
Accessibility	10	2	20	1	10	3	30
Total	100		275		180		145

B.6 Battery Mount

Table B.6: Battery Mount Configuration Criteria Analysis

Criteria	**Weight**	**Mounting Configuration**					
		Direct Mount to Chassis		**Indirect Mount to Chassis**		**Floor Mount via Sheet Metal**	
		S1	S1*W	S2	S2*W	S3	S3*W
Cost	15	3	45	2	30	1	15
Size	15	2	30	3	45	1	15
Weight	20	2	40	3	60	1	20
Reliability	25	2	50	3	75	1	25
Simplicity	15	2	30	1	15	3	45
Accessibility	10	2	20	3	30	1	10
Total	100		215		255		130

B.7 Suspension

Table B.7: Suspension Configuration Criteria Analysis

Criteria	**Weight**	**Suspension Configuration**					
		Push Suspension		**Pull Suspension**		**Double Wishbone**	
		S1	S1*W	S2	S2*W	S3	S3*W
Cost	5	3	15	3	15	4	20
Accessibility	25	5	125	3	75	4	100
Simplicity	20	4	80	2	40	4	80
Performance	15	5	75	5	75	3	45
Weight	10	3	30	4	40	2	20
Number of Parts	15	2	30	3	45	4	60
Reliability	10	3	30	3	30	2	20
Total	100		185		255		160