College of Engineering
Mechanical Engineering Department

System Description Document

ME 490W Engineering Design - Senior Project I
Project 18
Team MAM05-18-B
Race Car Ergonomics Jig (Phase II)

Aztec Ergonomics
Jakob Bravo, Zach Caceres-Batista, Sean Hedgecock, Alexandria Ng, Victor Velazco
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Team Members

Zachary Caceres-Batista

Sean Hedgecock

Jakob Bravo-Calderon

Victor Velazco

Alexandria Ng

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1.0 Project Description

1.1 Project Title: Race Car Ergonomics Jig (Phase II)

Since its formation in 2016, Aztec Electric Racing (AER) has been developing and iterating an electric race car for the annual Electric Vehicle (EV) Formula SAE (FSAE) competition. Driver ergonomics play a critical role in ensuring the safety of differently sized drivers operating the EV. The goal of this project is to design and manufacture a modular ergonomic jig that simulates various potential seating configurations within the race car– allowing AER to optimize the placement of key ergonomic components through physical evaluation, while meeting FSAE rulebook requirements. Figure 1. shows the current arrangement of components in the EV. AER has provided the computer-aided design (CAD) assembly files of their current race car as well as its components for design reference. The team was also additionally granted limited access to physical components of the EV, used during AER's regular team operations.

This jig will accommodate key components, such as the seat, steering wheel, pedal box, and harness attachments, ensuring regulation compliance and improving driver-EV interactions. The seating position is critical not only for driver comfort, but also for the efficient arrangement of components within the EV's chassis. The ergonomic jig will be designed to ensure customizable, variable seating that can continue to be utilized through regulation changes. The final design will allow the AER engineers to visualize and test the position of ergonomic components while being collapsible for storage within a standard 57-gallon bin. The final report will include driver body angles in comparison to present industry standards.

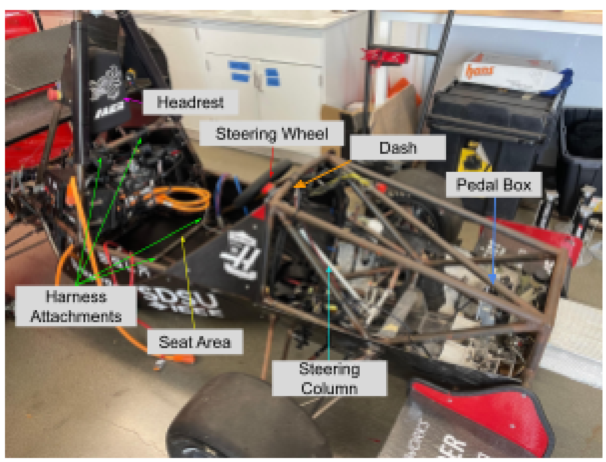

Figure 1: AER 2024 FSAE EV with exposed ergonomic modules

This project seeks to improve upon the previously built 2023 Phase I Ergonomics Jig, which did not fully satisfy the deliverables. The previous year's final design is shown in Figure 2. AER has provided access to files from the previous year to reference. Deliverables have been updated and the overall budget has been increased to match the inflation of project deliverables. The updated ergonomics jig will address issues with the prior design by incorporating quick-release mechanisms and allowing more intricate adjustments to each module. Another change being made will include multi-degree adjustment to the steering column and seat to better accommodate a wider range of angles.

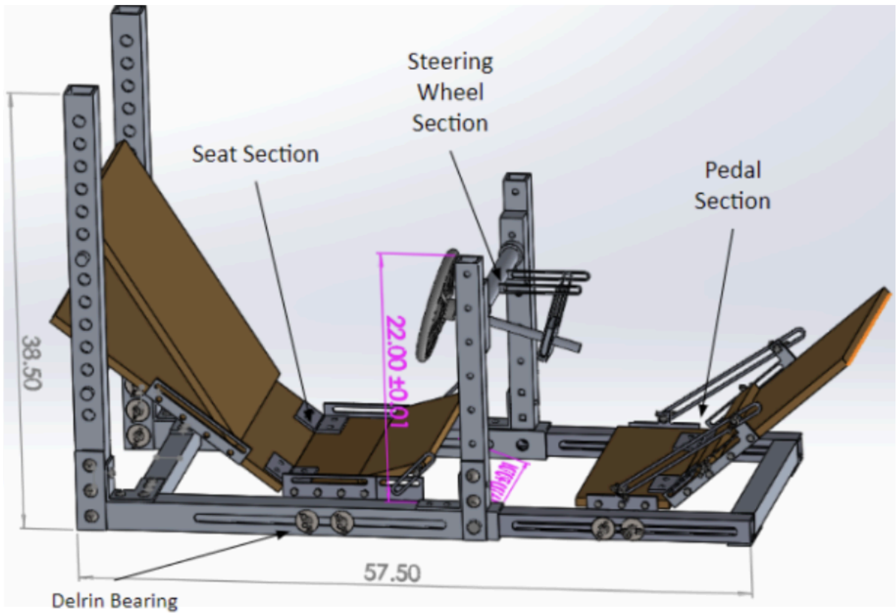

Figure 2: CAD model of Ergonomic Jig Phase I (Boskovich et al, n.d.)

The modular jig will allow precise adjustments to ergonomic modules, including the steering column, seat, headrest, pedal box, and dashboard, using a system of pins and retractable springs that lock into premeasured notches along the frame. These adjustments will accommodate drivers from the 5th female percentile to the 95th male percentile, ensuring compliance with the FSAE rulebook (Riley, 2015). Each module's position can be modified without compromising the structural integrity of the rig, maintaining the required rigidity for accurate positioning as per FSAE regulations. The jig will also facilitate testing for rule compliance, including driver egress (SAE International, 2024). An initial driver survey will gather feedback on adjustability, seat angles, pedalbox designs, steering rack shifting, and limb angles. This feedback shall help fine tune the overall layout while helping meet FSAE regulations for maximum comfort and safety. A second survey shall be issued to gather feedback on material selection in order to make a decision on the optimal materials that can be implemented into the jig, ensuring FSAE standards for material strength (SAE International, 2024). This survey shall highlight the use case for each material to decide which is the most favorable in terms of tensile strength and machinability. In regards to customizability, the jig will accommodate both current and future seat designs. The current seat will be mounted using front tabs that align with corresponding tabs on the frame and shall be secured with bolts. The back of the seat will connect to an adjustment mechanism that allows it to change its angle relative to the rest of the jig. Future seat designs will also have the ability to be easily mounted by integrating this flexible system.

The Aztec Ergonomics team shall work effectively and efficiently to create a modular jig that shall assist the Aztec Electric Racing team to iterate the design of current and future EVs. Periodically, the FSAE competition will adjust the rulebook and alter previously acceptable compliances. Our job shall be to create a tool that aids in making informed decisions on desirable locations to put the pedals, seat, steering wheel, and other effective driver positions for when a new chassis is created. With the modified jig and favorable adjustments that it shall be able to make along with pinpointing accurate measurements, our team shall be able to gather valuable data for when the driver takes a seat in the device. The key idea is to properly get that information and accurately translate it back to the design. The method we shall use to achieve this derives from the use of mapping geometric space along with interactive CAD modeling that allows for streamlined adjustments. Based on the scale of this jig our team shall use a master index system with measurements along specific points, like the rail where the seat is to be mounted. Then these measurements would be manually inputted into software that generates a spatial model or CAD model. This system would provide the most accurate placements of components based on the entered values. Although attempting to use 3D scanning for this is attractive, the index-and-measurement method shall be more feasible and provide a budget-friendly solution for generating necessary CAD models for our jig.

Table 1: Project Deliverables

Deliverable	Description	Due Date
System Description Document (SDD)	The document will provide an overview of the project's design, requirements, use cases, technical specifications, risks, and verification methods to outline the development process and project goals.	10/04/24
Project Management Plan (PMP)	A presentation summarizing the project’s problem statement, team structure, work breakdown, schedule through Gantt Chart, budget, risk management strategies, and key points.	10/11/24
Preliminary Design Report (PDR)	A document that provides a detailed overview of the project’s goals, initial research, design concepts, trade studies, analysis, manufacturing plans, prototypes, and risk assessment to guide the development and refinement of the preliminary design.	10/25/24
Critical Design Review	A presentation that reviews the final design. Will contain CAD drawings, design, engineering analysis, prototype results, assembly plans, and requirement verification plans.	12/11/24
Final Design Report	A document that details the project description, schedule with milestones, updated risk management cube, final design, lessons learned, drawings, and team labor hours.	12/11/24
Manufacturing Review	A document with engineering drawings and a manufacturing timeline.	Early February
Test Review	Tests showing results from prototype evaluations.	Middle of March
Final Presentation & Demonstration	Presentation of project and demonstration of the system.	End of April
SDSU Design Day	Presentation at Viejas Arena (in years past) of completed design and the work that went into it.	Early May

1.2 Senior Design Team: Aztec Ergonomics

Table 2: Team Information

Team Member	Role	Email
Jakob Bravo Calderon	Mechanical Engineer	jbravocalderon2030@sdsu.edu
Zach Caceres-Batista	Mechanical Engineer	zcaceresbatist1877@sdsu.edu
Sean Headgecock	Mechanical Engineer	shedgecock5567@sdsu.edu
Alexandra Ng	Team Lead	ang4927@sdsu.edu
Victor Velazco	Mechanical Engineer	vvelazco1162@sdsu.edu

1.3 Project Sponsor: Aztec Electric Racing

Table 3: AER Sponsor Team

Aztec Electric Racing Website: https://aztecelectricracing.sdsu.edu/		
AER Contact	Role	Email
Sofia Goulart	President	sgoulart1321@sdsu.edu
Georgie Rauls	Ergonomics Lead	grauls2635@sdsu.edu
Charlie Webb	Chief Mechanical Engineer	cwebb7395@sdsu.edu

2.0 Use Case

The ergonomic jig is designed to simulate the seating arrangement of the AER EV, allowing for precise module adjustments to accommodate drivers of various sizes in line with rule V.2.1.1 (SAE International, 2024). Key adjustable components include the seat, steering wheel, steering column, head rest, pedal box, harness attachments, and dashboard. These elements will be customizable through a system of pins and retractable springs, enabling adjustments that will suit a wide range of driver body dimensions and preferences.

The ergonomic jig will ensure that drivers can achieve an ergonomic driving posture. To comply with FSAE steering rules, drivers must sit comfortably with their knees flexed appropriately relevant to the pedal box placement and with their arms positioned at a 90° angle (T.2.3.1) (SAE International, 2024). The pedal box is a key adjustable component as it accommodates both the 5th percentile female (4’11”, 113 lbs) and the 95th percentile male (6' 2”, 246 lbs), adhering to anthropometric data standards (S.4) (Riley, 2015). Utilizing this system, a given driver should be able to reach the pedal box without strain, after careful adjustment. Additionally, the jig shall make sure that the driver can easily turn the steering wheel without interference from their legs.

The entire jig setup shall be used to gather feedback on driver ergonomics, seating comfort, and control accessibility through a series of surveys. The surveys shall collect data on adjustability needs, limb angles, seating positions, driver comfort, and assisting in fine tuning the seat and control layout for optimal comfort. After the driver’s optimal seating position is set, the modular jig shall help test compliance with the 2024 FSAE rulebook. Two critical areas that need attention are the driver egress (R-05) and rollover protection (F.1.13) (SAE International, 2024). A second survey shall be conducted to guide material selection for the jig’s components for durability and ease of use (F.3.2) (SAE International, 2024). The design must accommodate current and future seat designs using front mounting tabs and a pivoting mechanism at the rear to adjust the seat angle (T.2.5) (SAE International, 2024). The key is to design a tool that can be used despite the ongoing improvements made to the electric race car designs while maintaining accurate, repeatable measurements for component placement. Figures 4 through 6 reenact Aztec Ergonomics’ engineering solutions to AER’s development process.

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2.1 Storyboard Concept

(1.)

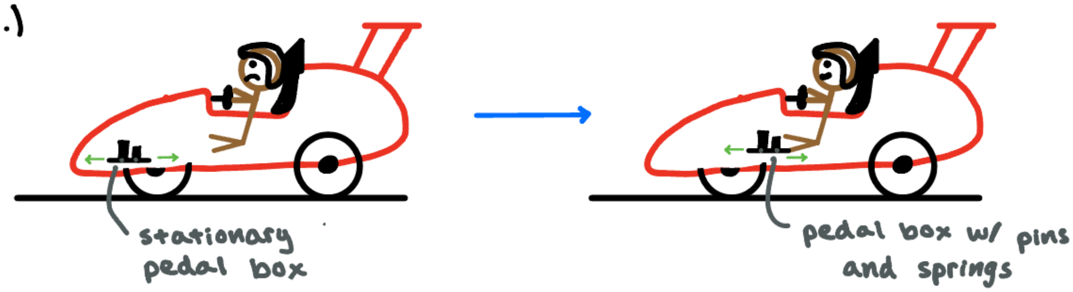

Figure 3: Storyboard Pedal Box

(2.)

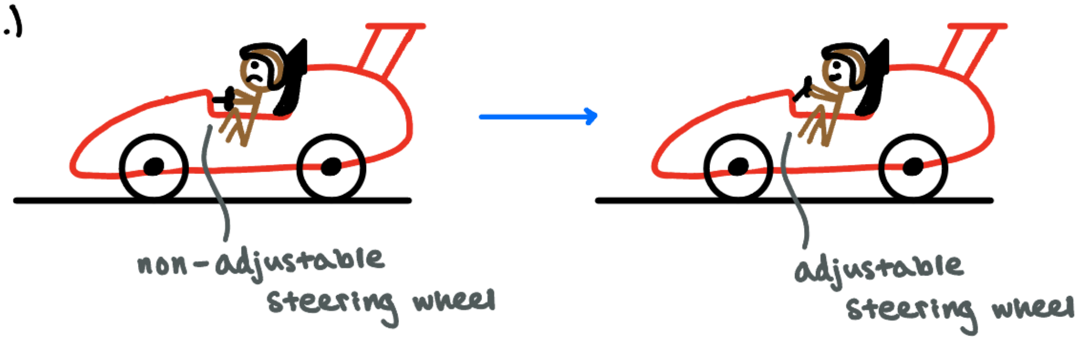

Figure 4: Storyboard Steering Wheel

(3.)

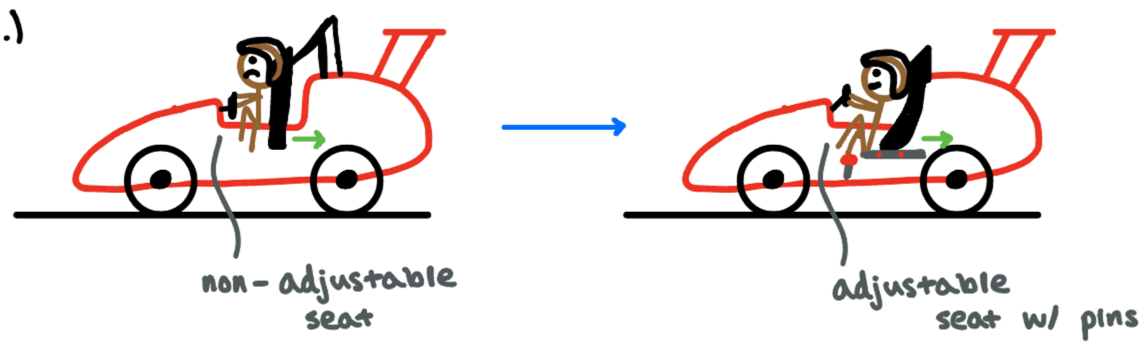

Figure 5: Storyboard Adjustable Seat

(4.)

Figure 6: Storyboard Finished Design

3.0 System Requirements and Engineering Specifications

The design requirement parameters for the modular ergonomic jig are vital to provide both safety and performance, coming directly from industry standards as well as the FSAE rulebook on competition requirements (SAE International, 2024). Table 4 details the requirements, their respective engineering specifications, and the priority level assigned to each based on the importance of the parameter to the overall design. Each requirement is linked to specific design objectives, and the final design must ensure that these objectives are achieved in both competition and safety compliance.

The primary objective for rollover compliance is to have the vehicle meet all safety standards and can withstand impact during a rollover event without endangering the driver. For egress, the vehicle must allow the driver to exit the car quickly and safely in case of an emergency. It should take the driver about five seconds to unbuckle and unhook the steering wheel. These requirements are essential for competition and driver safety during real-world testing and operation.

Based on the project goal to create a modular ergonomic jig for AER, and the project description, key design requirements are listed as follows: driver accommodation including adjustability, driver egress, cockpit, and internal cross section along with seating position. Safety and driver protection including driver's feet and legs, and control accessibility. Component positioning and adjustment including modular design, and pedal assembly. Construction and structural requirements including cockpit template criteria, and safety requirements (IN.6) (SAE International, 2024). These requirements are listed along with descriptions and their respective codes.

Table 4: System Requirements and Engineering Specifications

Requirement Number	Design Objective	Priority Level (1-3)	Design Requirement	Engineering Specification	Justification	Source
R-01	1,2	1	The jig shall accommodate 5th percentile female to 95th percentile male	The jig shall allow adjustments to accommodate a driver height range of 4'11" (151.5 cms) to 6'2" (186.5 cms)	To ensures the jig provides safe operation for all drivers while being adjustable to fit specified driver templates	Sponsor Requirement / FSAE Online Website Anthropometric data [V.2.1.1]
				This includes adjustments to the seat, steering wheel, and pedal box positions to fit a variety of body dimensions		
R-02	1	1	The jig shall be designed around the current AER chassis and FSAE EV rulebook	The jig must allow placement of the bottom 200 mm circle on the seat bottom, ensuring a distance of at least 915 mm between the circle's center and the pedal's rearmost face. It shall allow for a maximum 25 mm offset between the upper circle and head restraint	Ensures compatibility and compliance	Sponsor Requirement / FSAE Rules [F.4] [F.5]
				The jig must be designed to meet or demonstrate equivalence to the structural integrity of a chassis made from steel tubing by including calculations for energy dissipation, yield strength, and ultimate strengths in bending, buckling, and tension		
R-03	2	2	Shall be a modular design with future integration capabilities	The jig must include mounting points and supports compatible with steel, alternative tubing, and composite material configurations	Supports future vehicle iterations	Sponsor Requirement / FSAE Rules [F.5] [V.2.1.1]
				The jig should allow for variations in seat position, steering column, and pedal box placements to test different configurations		
R-04	1,2	1	The system shall use materials that create rigid	The Brake Pedal and associated components design must withstand a minimum	Ensures repeatable accuracy	Sponsor Requirement / FSAE Rules

			component accuracy	force of 2000 N without any failure of the Brake System, pedal box, chassis mounting, or pedal adjustment		[T.3.2] [F.4]
				The jig must include methods to assess any holes in regulated tubing and ensure they comply with the specifications outlined in the Structural Equivalency Spreadsheet (SES)		
				If the jig uses composite or non-standard materials, it must include documentation of the material type, properties, manufacturing technique, and construction dates		
R-05	1	2	Shall test egress per 2025 FSAE rulebook	Each driver must be able to exit to the side of the vehicle in no more than 5 seconds	Complies with driver safety standards	Sponsor Requirement / FSAE Rules [IN.5.2]
				The jig must simulate the space and accessibility to cockpit controls (IC Cockpit Main Switch for IC vehicles or EV Shutdown Button for EV vehicles)		
R-06	2	2	Shall be collapsible for storage within 57-gallon tub	The jig shall be designed to collapse into dimensions that fit within a storage tub measuring 31.9 inches x 18.6 inches x 13.7 inches	Allows for storage and transport	Sponsor Requirement
R-07	1	3	Shall test compliance with 2025 FSAE rulebook	Must support configurations that comply with technical inspection requirements, allowing for a complete evaluation of items listed in the Technical Inspection Form	Ensures design meets all regulations	Sponsor Requirement / FSAE Rules [IN.2] [IN.7]
R-08	1,2	2	Shall be mountable for current and future AER seats	The jig must enable the seat to be grommeted or rolled at points where belts or harnesses pass through	Supports testing with various seat designs	Sponsor Requirement / FSAE Rules [T.2.5.3]
R-09	2	1	Cost shall not exceed $2,500	Total budget for materials and components is $2,500	Stays within financial constraints	Sponsor Requirement

R-10	1	3	The final report shall include driver body angles	The report shall provide data on driver body angles, seat positioning, and control ergonomics, illustrating how these design aspects meet ergonomic requirements	Required for design presentation	Sponsor Requirement / FSAE Online Website Anthropometri c data [S.4]
				The jig shall incorporate a master index system with notched measurements along specific points, such as the rails where body angles can be measured		
R-11	1,2	1	In the event of a rollover driver safety is ensured	The driver's head and hands must not contact the ground in any rollover attitude	The vehicle must be able to absorb the impact and prevent collapse	Safety Requirement / FSAE Rules [V.2.1.2]
				Must include a rollover protection envelope that consists of the primary structure		
R-12	1,2	1	The jig shall adhere to harness strap requirements	The jig must allow for harness fitting with the seat back angled at 30° or less from vertical, measured along the line joining the two 200 mm circles of the 95th percentile male template	Provides driver safety during operation	Safety Requirement / FSAE Rules [T.2] [IN.5]
				The jig must also accommodate harness fitting with the seat back angled at more than 30° from vertical, measured in the same way		
R-13	1	1	The jig shall pass the template test with sheet metal template	Will be held vertically and inserted into the cockpit opening rearward of the rearmost portion of the steering column	Verifies the design meets cockpit size and clearance rules	Sponsor Requirement / FSAE Rules [T.1]
				Will then be passed horizontally through the cockpit to a point 100 mm rearwards of the face of the rearmost pedal when in the inoperative position		

The rollover compliance requirements focus on ensuring the vehicle maintains structural integrity during a rollover event. The roll hoop must be designed and tested to withstand impact forces without deformation which could harm the driver. Material selection and geometric constraints are important in meeting these objectives. The roll hoop height and material strength are two of the most important factors when it comes to protecting the driver in the event of an accident. The material must meet minimum yield strength requirements to avoid factures. Egress requirements are centered around driver safety and compliance with quick exit standards. The driver must be able to exit the vehicle within 5 seconds without assistance, ensuring a quick response in case of fire, mechanical failure, or any other emergency (R-05) (SAE International, 2024). This requirement directly impacts the design of the cockpit and harness systems, which must be easy to release to allow for rapid driver movement. Egress accessibility is further supported by the need for no-tool exits, which simplifies the process and minimizes delay.

The design must account for ease of manufacturing and inspection. Additionally, the design must allow for inspection to confirm that it complies with competition rules, while also being reasonable to manufacture with tight tolerances. The main idea behind this requirement is that it remains functional and compliant throughout its lifecycle. Since the vehicle shall be used in various environments, material selection must account for durability under varying conditions such as high heat and stress (F.3.2) (SAE International, 2024). Components must resist corrosion and fatigue over time to have the system remaining reliable throughout multiple tests and events.

4.0 Technical Risks

4.1 Risk Mitigation:

A risk mitigation chart is essential as it outlines multiple if-then scenarios to categorize the severity of potential issues that may arise during our project and outlines strategies to prevent these risks. The chart emphasizes the importance of risk management by assigning a numerical scale from 1 to 5, where 1 represents the least critical and 5 representing the most significant risk. These numbers are used to assess the likelihood of each projected risk occurring and the severity of its impact if overlooked. The chart also includes a risk mitigation plan to address and prevent the occurrence of these risks.

Likelihood	**5**					
	4					
	3				6	5
	2				1	2, 3
	1			4, 8	7	
		1	**2**	**3**	**4**	**5**
		Consequences				

Figure 7: Risk Mitigation Cube

Table 5: Risk Mitigation Table

No.	Risk Management	Risk Analysis		Risk Mitigation Plan
		Likelihood	Consequence	
1	If any team members fail to complete their assignments or provide support to the project, then the project shall be delayed, causing deadlines to be pushed back.	2	4	Scheduling weekly team meetings shall help evaluate current assignments and ensure that everyone is on track or in need of assistance.
2	If engineering design models and calculations are not done correctly, then the prototype model shall not yield optimal results.	2	5	A thorough review of calculations by one or more team members, along with input from the professor, can help verify the accuracy of results and prevent incorrect analysis.
3	If materials do not arrive as specified and on time, then the project cannot be manufactured correctly and completed on schedule.	2	5	All ordered items must be inspected to ensure their quality and timely arrival.
4	If the budget is exceeded, then the project may face severe delays until additional funds are secured.	1	3	A spending plan should be established to prevent exceeding the budget, with a portion allocated as emergency funds in case the project requires significant change.
5	If the adjustable elements on the prototype do not operate smoothly, then issues may arise during full-scale testing.	3	5	The team shall conduct through testing and refinement of the adjustable elements on the prototype before full-scale modeling.
6	If fabrication issues arise when constructing parts, then it shall lead to material waste during the production process, resulting in extended processing times and delays throughout the project.	3	4	Learning how to operate any machinery and seeking assistance from the professor and Aztec Electric Racing Team shall prevent issues when addressing any fabrication needs.
7	If design specifications are	1	4	Regular communication between

	poorly defined, then there shall be errors in design and it may not meet all of the sponsor's requirements.			the team sponsor shall be maintained through meetings and emails to ensure all team members are aligned with the sponsor's specifications and that any uncertainties are addressed promptly.
8	If materials are lost, damaged, or stolen, then the team shall be unable to manufacture the ergonomic jig until replacements are bought.	1	3	All materials shall be stored behind a locked cabinet that shall only be accessed by project team members and the Aztec Electric Racing team.

5.0 Requirements Verification Methods

Various requirements are to be tested and evaluated (T&E). These requirements and their methods of verification are shown in the table below. The table displays the requirement number, requirement, requirement specification, and validation method.

Table 6: Requirements and Validation Methods

Requirement Number	Requirement	D	T	A	Verification Plan	Complete By
R-01	The jig shall accommodate 5th percentile female to 95th percentile male			X	Calculations shall be made to fit both extremes in the cockpit properly.	Fall
R-02	The jig shall be designed around the current AER chassis and FSAE EV rulebook	X			Before fabrication, the CAD design shall be inspected to ensure proper dimensions and tolerances. An inspection shall be done to ensure rules compliance according to the 2025 FSAE EV rulebook and ensure similarity to crucial components of AER's chassis.	Fall/Spring
R-03	The jig shall have a modular design and the ability to integrate future designs	X			Before fabrication, the CAD assembly shall be modular. The final design shall be inspected to ensure the ability to break down.	Fall/Spring
R-04	The jig shall be rigid enough to ensure component location accuracy over time	X			Prototypes shall be tested for rigidity using various methods and the final design shall be inspected for rigidity based on sudden movements and disassembly.	Fall/Spring
R-05	The jig shall be able to test egress according to the 2025 FSAE EV rulebook [T.4.8]	X			Prototypes of the leg bar shall be tested. Demonstration of the final design's egress testability shall be conducted.	Fall/Spring
R-06	The design shall be collapsible and able to be stored in a 57-gallon bin	X	X	X	Solidworks dimensions and tolerances shall be analyzed for compatibility with 31.9 in by 18.6 in by 13.7 in tub. Prototypes shall be made representative of the proposed size and tested. The final design shall demonstrate collapsibility and storage.	Fall/Spring

R-07	The jig shall be able to test for rules compliance within the 2025 FSAE EV rulebook	X			A demonstration shall be run through all desired rules compliance tests such as rollover and egress.	Spring
R-08	The current and future AER seats shall be mountable	X			A demonstration of the jig's model seat being capable of being switched with the current seat shall be completed.	Spring
R-09	The total cost shall not exceed $2,500			X	A cost analysis shall be conducted after the project is completed to ensure the budget was not exceeded.	Spring
R-10	The final report and jig shall include marked driver body angles and how they compare with industry standards	X			An inspection of the final report shall show body angle information and comparisons with industry standards. Additionally, an inspection of the final jig shall show a legend of body angles.	Spring
R-11	The jig shall be able to test that structural integrity is maintained under a 5g impact during a rollover event			X	Mathematical analysis shall be completed to display that the rig can maintain structural integrity during a 5-gram impact during a rollover event.	Fall
R-12	The harness shall be positioned and attached according to FSAE EV rules	X			An inspection of the final design shall show harness alignment and rules compliance.	Spring
R-13	The cockpit shall allow a metal template to fit throughout per FSAE EV rules	X			An inspection of the final report shall demonstrate the metal template test being conducted.	Spring

Nomenclature: "D" means Demonstration, "T" means Test, and "A" means Analysis

The completed project will consist of a full-scale ergonomic jig with mock components representing its counterpart in AER's EV. A final report will document the measurements collected from the jig, ensuring these measurements can be used for future car design iterations. A majority of the project requirements will be validated through physical demonstrations that verify the geometry and adaptability of the jig. Some requirements will be validated through prototype testing and mathematical or element analysis.

Validation by demonstration shall involve inspecting the CAD drawings of the ergonomic jig and the final product to ensure they accurately represent the intended design. The CAD design shall ideally be fully representative of the final design's dimensions and tolerances. Most of the inspection shall occur to show completion of FSAE EV rulebook testing requirements and geometric requirements set by AER and the FSAE EV rulebook.

The design's capability to be stored in a 57-gallon storage bin shall be validated through testing. To show the possibility of this, a prototype constructed of full scale parts representative to the design will be fit into a 57-gallon storage bin. This requirement (R-06) shall be further validated using analysis and demonstration using the final design.

Several requirements will be verified through mathematical analysis. Mathematical computations of the cockpit's size accommodation shall be completed and shall prove fitting (V.2.1.1), and calculations shall be completed to prove structural integrity is maintained during rollover (V.2.1.2). Geometrical analysis shall also be conducted for the design's ability to fit and collapse within a 57-gallon storage bin (R-06). Economic analysis shall be conducted to prove the design did not exceed the budget (R-09).

All validation methods are subject to an increase in scope but shall not be omitted or decreased in scope.

References

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