Assessment of Ergonomic Studies in the Design of an Off Road Vehicle

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This article presents an ergonomic assessment performed in the CL-02 prototype in the Baja Society of Automotive Engineers (SAE) Brazil competition. Using computer simulations in Computer Aided Tridimensional Interactive Application (CATIA) software and physical validations through a full-scale mockup, the project aimed to ensure comfort and safety for drivers with different body types. Postural analysis was performed using the Rapid Upper Limb Assessment (RULA) method and photogrammetry, involving drivers representing the first percentile, forty-second percentile, ninety-ninth percentile. The ergonomic evaluation determined precise spatial relationships between the driver and key vehicle components, including distances to the steering wheel, pedals, and seat reference points. These measurements highlight a layout that supports comfort and efficiency, with optimized posture through backrest inclination and steering wheel positioning. The methodology also allowed for the identification of improvement opportunities for future projects, such as fine-tuning the pedal position. The study reinforces the importance of integrating ergonomics and engineering from the early stages of design.

Keywords: Baja SAE. Ergonomics. RULA.

Abbreviations: CATIA, Computer Aided Tridimensional Interactive Application. CL-01, CalangoTec 01 Prototype. CL-02, CalangoTec 02 Prototype. PPE, Personal Protective Equipment. RULA, Rapid Upper Limb Assessment. SAE, Society of Automotive Engineers.

Ergonomics is defined as the science that studies the interactions between humans and the elements of the systems in which they operate, using principles and data to optimize human well-being and overall system performance, as described by Iida, 2005 [1]. In the context of the development of single-seat vehicles for competitions such as Baja SAE, ergonomics became a relevant factor, since the driver remained in the driving position for extended periods, being subjected to constant vibrations, and the need for full control of the vehicle.

Design ergonomics was incorporated from the beginning stages of the prototype project of prototype, which allowed the adjustment of dimensions and geometries to different users, as described by Huet and Moraes, 2003 [2]. Rules, by Baja SAE Brazil competition, 2025 [3], required the vehicles be capable of accommodating different drivers (different heights and weights), ensuring a minimum space for the driver equipped with all Personal Protective Equipment (PPE) (such as arm restraints, helmet, neck brace, gloves, and closed shoes), positioned in cockpit. Such regulatory requirements demand projects using structural safety, and also anthropometric and functional aspects.

During the development process of CL-02 prototype, different anthropometric profiles of the drivers were analyzed (considering body size measurements, and members proportions). The comfort during driving was evaluated, as well as mobility with the safety harness fastened, the ease of prototype access, and car operation without requiring awkward postures. Studies such as those by Guedes and colleagues (2018) [4] demonstrate the use of digital tools, such as the CATIA software, enabled the preliminary evaluation of the pilot's postural suitability and functional reach. Furthermore, Santos and colleagues (2021) [5] showed that adjustments to components such as the seat, pedals, and controls directly affected

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comfort and safety. Conversely, Huet and Moraes, 2003 [2] warned that neglecting these aspects could lead to improper postures and prolonged physical discomfort. Additionally, Walker, 2017 [6] emphasized that poorly designed ergonomic projects could impair the driver's situational awareness, thereby increasing operational risks.

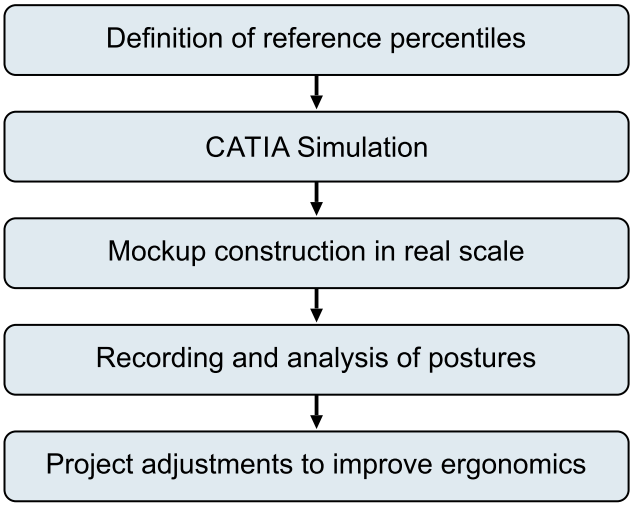
The objective of this article was to evaluate an ergonomic study applied to different individuals (covering a range between 1.59 m to 1.94 m) and weight (55 kg to 95 kg) ensuring that key joint angles such as those of the knee, hip, and elbow, were all kept within the parameters established according to Tilley, 2002 [7] and McAtamney and Corlett, 1993 [8]. The CATIA software and the RULA method were used for postural assessment.

Materials and Methods

Several elements related to vehicle seating, essential to ensuring an ergonomic and comfortable posture, were considered as the basis for the evolution of the ergonomic design applied to the CL-01 prototype (2023), with the goal of significantly enhancing its application in the new CL-02 model, under development for the 2025 season. The approach used in this work followed the scheme observed in Figure 1.

To ensure the accommodation of drivers with different profiles, the extreme percentiles of different drivers were used as reference: the ninety-ninth percentile male and the first percentile female. According to the BAJA SAE Brazil, 2025 [3], the vehicle must to accommodate drivers ranging from 1.90 m and 109 kg, to 1.45 m and 42 kg, in height and weight respectively.The profiles analyzed in this work were 1.94 m and 95 kg, 1.59 m and 55 kg, also an intermediate driver (1.75 m and 75 kg), representing the forty-second percentile. The initial analysis was carried out in CATIA software, including RULA analysis, through the simulation of driving positions, covering aspects such as range of motion of arms and legs, angle between the backrest and seat, reach of the controls, and forward visibility (Figure 2).

Figure 1. Visual representation of the method.



After the computational simulations, using the ideal measurements described by Tilley (2002) [7], it was made a full-scale physical mockup to validate the virtual prototype. This validation allowed for important adjustments to the roll cage geometry, including increased internal space, repositioning of the pedals, and changes to the seat height and inclination (Table 1).

Table 1. Ideal measurements.

Body member	Measure
Knees	110° - 120°
Seat - Backrest	95°
Leg - Backbone	95° - 100°
Arm	115°
Ankle	100°

Source: Adapted from Tilley (2002) [7].

The RULA analysis (Table 2), is an ergonomic tool used to assess the risk of musculoskeletal injuries related to the drivers posture. It provides a score based on the position of the upper limbs, trunk, and neck during the driving. Using the final score, it is possible to determine the level of risk and, consequently, the degree of ergonomic reliability of the analyzed position, as described by McAtamney and Corlett (1993) [8].

Figure 2. Digital model of ergonomic simulation in CATIA with first (a), ninety-ninth (b), and forty-second (c) percentile drivers.

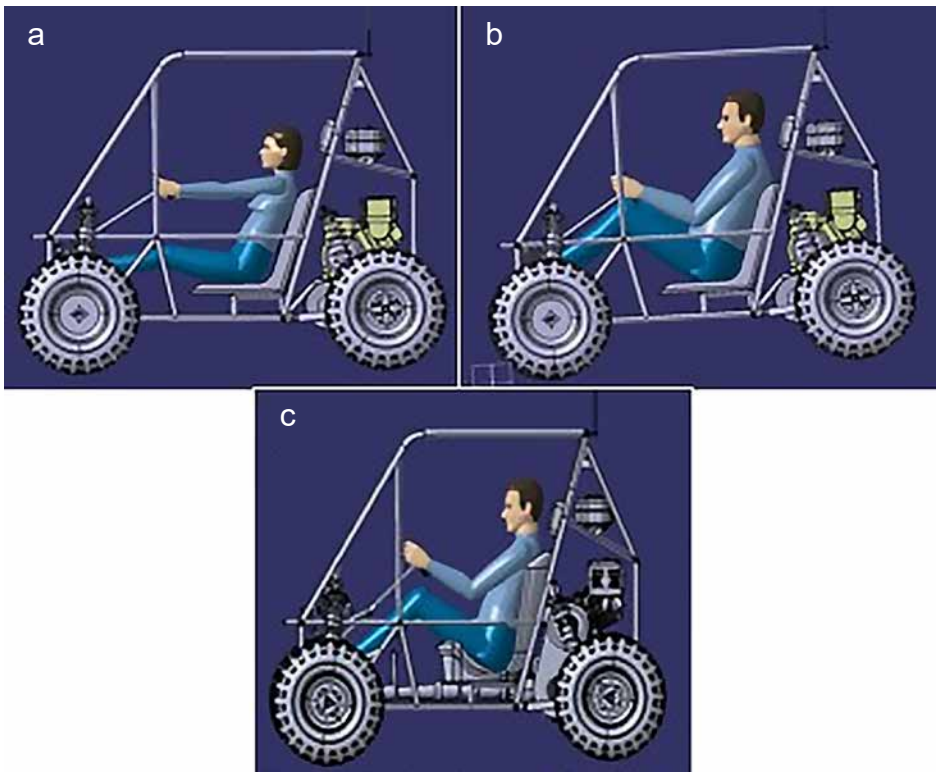


Table 2. RULA analysis.

Score	Action Level	Intervention
1 or 2	1	Acceptable posture.
3 or 4	2	An observation should be made and changes may be necessary.
5 or 6	3	An investigation must be carried out and changes must be introduced.
7	4	Changes must be introduced immediately.

Source: Adapted by McAtamney and Corlett (1993) [8].

Using information from Table 1, a photogrammetry was carried out to analyze the posture of drivers, as observed in Figures 3 and 4. The technique consisted of analyzing photographic images to obtain measurements and body distances relevant to the project's ergonomics. These same drivers took part in the practical tests, ensuring the necessary representativeness for validation. After reaching a consensus among the users, the ergonomic modifications were incorporated into the final project, and the structure's manufacturing was initiated.

Results and Discussion

The simulations performed in the CATIA software, together with tests using a physical mockup, showed the ergonomic suitability of the CL-02 vehicle for different body types. The RULA analysis (Table 3) indicated risk levels classified low to moderate.

Photogrammetry validated the decisions made in the simulations, such as increasing interior space and repositioning the seat and pedals, ensuring comfort and proper driving posture. During the

Figure 3. Photogrammetry of the first percentile female and ninety-ninth percentile male in the ergonomic mockup.

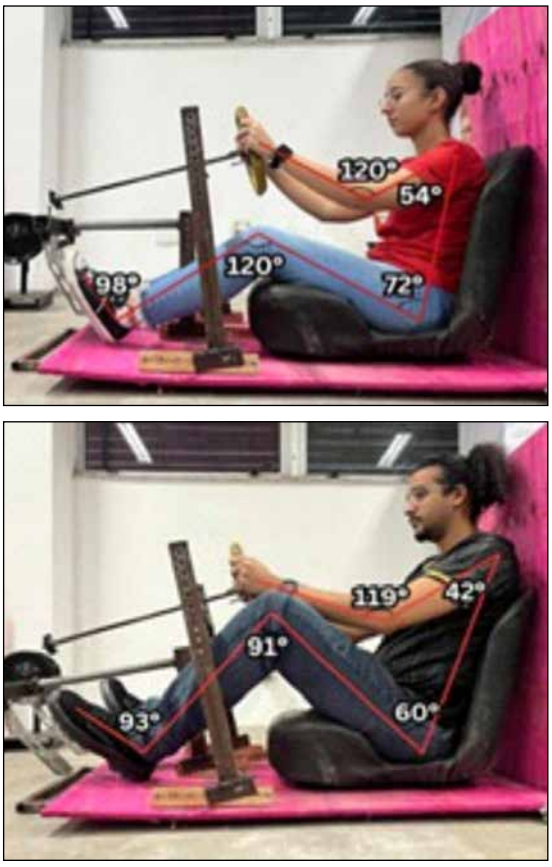


Figure 4. Photogrammetry of the forty-second percentile male (titular drivers) in the ergonomic mockup.

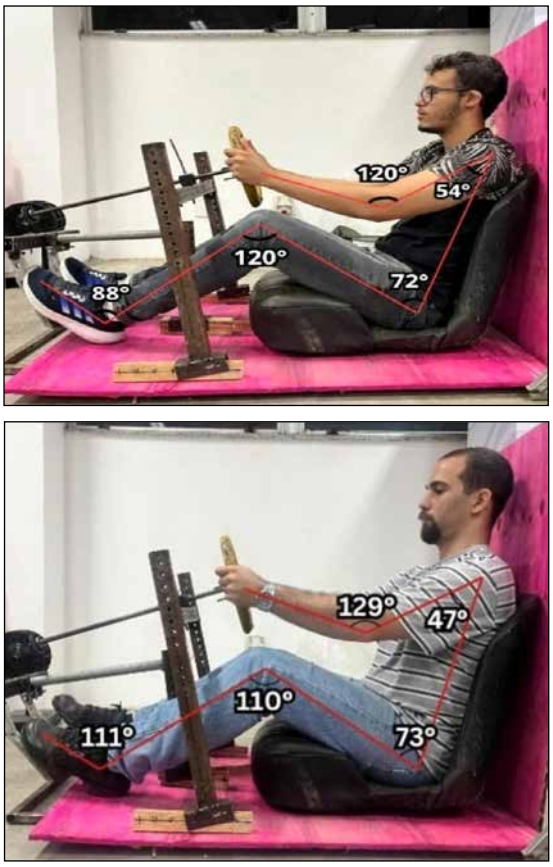


Table 3. RULA analysis scores.

Pilot	Score
1 percentile female	3
42 percentile male	3
99 percentile male	3

tests, all evaluated percentiles reported adequate comfort, demonstrating that the design allowed efficient and safe accommodation for different body types (Figures 5 to 7).

Based on the analysis of the extreme and drivers average percentile, the main ergonomic dimensions of the CL-02 cockpit were defined to ensure a comfortable and functional driving position. The distance between the firewall and the center of the steering wheel was determined to be 562.50 mm, while the distance to the pedals was 930 mm. The foot support plane presented a height difference of approximately 90 mm relative to the seat, and the backrest was designed with an inclination of 17° with respect to the seat base, promoting a relaxed and efficient posture. The steering wheel was positioned 518 mm above the seat base, and the horizontal distance between the backrest and the steering wheel axis was 621.50 mm.

These dimensions ensured that the joint angles of the knees, elbows, and hips remain within the ergonomic limits recommended by Tilley, 2002 [7], following the Baja SAE standards and promoting safety and comfort during driving.

Figure 5. Photogrammetry of the first percentile female in cockpit prototype.

Figure 6. Photogrammetry of the forty-second percentile male in cockpit prototype.

Figure 7. Photogrammetry of the ninety-ninth percentile male in cockpit prototype.

Conclusion

The approach adopted in the CL-02 project proved effective in producing an ergonomically appropriate vehicle despite the anthropometric diversity of its drivers. The combination of simulations, postural analysis, and practical validation enabled safety and good decisions throughout prototype development.

Despite minor limitations identified for the 1% percentile, the design met the criteria for comfort and usability, particularly for the drivers average percentile.

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