Defining the ergonomic parameters of the driver's seat in a competition single-seater

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Abstract: This paper sets out a design methodology for the cockpit of a competition vehicle that applies ergonomic criteria. Through a practical design case of a Formula SAE single-seater, a methodology is proposed that ranges from taking anthropometric measurements of the comfort posture of a population of 22 possible drivers to the use of an ergonomic module of a three-dimensional (3D) design program and the construction of the chassis and the driver's seat. This methodology, which can be used in other different applications, is at all times documented with the results obtained from measurements, with the parameters used in the design and with photographs that capture the data collection and manufacturing process.

Keywords: ergonomic; competition single-seater; driver's seat; cockpit; comfort; formula SAE.

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1 Introduction

Although there is a considerable bibliography on the best posture for people to adopt to do different jobs (Hanson et al., 2006; Porter and Gyi, 1998; Kyung et al., 2008), the number of references becomes fewer, as more specific and unusual activities are dealt with. This is the case with the ergonomics of a competition single-seater cockpit. Competitions with adapted private cars (World Rally Championship, Private Car Road Championships of different makes, etc.) benefit from a driving position similar to that of motor vehicles, but a single-seater formula design cockpit must start out from a different position, usually more reclined.

This position is partly due, on the one hand, to the aerodynamic requirements of the vehicle, and, on the other hand, to the need to lower the single-seater's centre of gravity to the maximum.

The vibrations transmitted from the road to the driver through a necessarily hard suspension, as well as the high inertias exerted on the driver by the speed, mean that a detailed ergonomics study is necessary if the appearance of fatigue or even injuries are to be avoided while driving (Baur et al., 2006). Most of the bruises or injuries occur in the limbs and in some post-race cases the driver presents symptoms of inability to raise his arms accordingly (Minoyama and Tsuchida, 2004).

The participation of a team from Madrid Polytechnic University, the UPM, led by the University Institute for Automobile Research, INSIA, in the Formula SAE competition, created the right conditions for a group of teachers and students lacking in any prior documentation for this application to confront the need to design a competition single-seat car.

The lack of any clear bibliography in this respect (Jawad and Mariotti, 2000) and the impossibility to use any specific databases (Hunn, 1998) due to the confidentiality under which competition businesses and teams guard their researches, led the UPMracing team to develop a simple methodology based on You's work (You et al., 1997). An important database was also created of measurements, comfortable postures, acceptable ranges, etc., with feedback of custom questionnaires to the drivers who had taken part in the specially built simulators and the competition track trials.

The entire process of data collection, design and results analysis was rigorously documented, and has already been used to develop other competition single-seaters.

2 Designing the cockpit for a competition vehicle

There are many factors that cause the cockpit design parameters and functional requirements of a competition vehicle to differ greatly from those of a passenger car. On the one hand, driving a competition vehicle is a more active and demanding task than a normal vehicle: the driver needs greater concentration, makes more sudden movements and is subjected to considerable accelerations/decelerations both longitudinal and transversal. In addition, the vibrations endured due to the speed and hardness of the suspension means that the threshold of what would be acceptable in another type of vehicle is exceeded.

Ergonomic requirements may be grouped into physical, such as the dimensions and position of the seat, and perceptual, such as the visibility of the control panel (Ouidir et al., 2008).

Also, particularly in formula-type single-seaters, the interior space is much smaller, the upper part is open to the outside and the driver's posture is conditioned by the need to reduce the vehicle's centre of gravity, which means the driver is in a highly reclined posture with his legs stretching forward. A large part of the design restrictions of the cockpit are laid down by international regulations, like those of the International Automobile Federation, the FIA. These regulations and recommendations are mainly aimed at ensuring driver safety in the event of an accident. In addition to the rigidity of the chassis or the presence of elements such as safety arcs or the firewall separating the engine zone, the regulations also lay down characteristics such as the height of the side bars to protect the driver's arms and shoulders.

In addition to meeting these kinds of requirements, some perceptual features must be taken into account: driving a single-seater demands the driver's whole attention at every instant and his peripheral vision is hindered by the use of a helmet, the information received via the display is also hindered (Verwey, 2000; Matthews, 2002). This is why the design of the control and communication interfaces is a key issue so that they do not distract the driver's attention through being located at a position distant from the line of vision or because they offer information that is not essential for driving.

One issue to be borne in mind is how limited any possible movements of the driver are: with a moulded seat fitted with a 5 or 6 point harness that literally clamps the driver down, and with such a narrow cockpit, leg movement is simply reduced to operating the pedals, while the arms are limited to moving the steering wheel and a few other things. Although almost all single-seater competition cars are fitted with sequential gearboxes with the gear lever on the steering wheel, in cars that have a manual gear change, the position and path of the gear lever have to be closely studied so that the hand is off the wheel for as little as possible and so that the effects of inertias on the arm as it passes from one element to another are minimised.

Conditions of comfort are, therefore, very different. The three components that can usually be modified to adapt to different sizes of drivers are the seat, the steering wheel and the pedals. Therefore, the ergonomics designer, in accordance with the specifications of the other vehicle systems, has to decide what components in each vehicle need to be adjustable and which can be fixed regardless of the driver's size.

Although the high inertias to which a driver is subjected suggest the cockpit design should be very narrow (Figure 1) in addition to appropriate manoeuvrability, safety regulations also require a driver to be able to get out of a car by himself in a short space of time (Andreoni et al., 2004; Galer et al. 1999), usually 5 sec. In this time, the driver must be able to disconnect the steering wheel, put it outside the car, free the harness, get his arms out the cockpit to support himself, stand up on the seat and jump out of the vehicle.

Figure 1 Formula1 cockpit

For all these reasons, it is of vital importance to analyse the driver's driving position and design the cockpit by applying rigorous ergonomics criteria. If this is not done, the driver can suffer discomfort, acceleration fatigue or injuries derived from a poor posture, from high vibration and inertia thresholds or simply from banging against some parts of the chassis or inside panels.

Therefore, the essential parameters to be studied for ergonomic cockpit design are as follows:

- Visibility with regard to the road and instrument panel
- Forces and vibrations acting on the driver
- Driver's posture and seat shape
- Controls within reach (steering wheel, gears and pedals)
- Interior space and volume necessary to avoid interferences and impacts
- Cockpit accessibility, particularly for its evacuation.

According to the experience of our Institute in the design of single-seaters, a good approach is to design it by working from the driver to the outside. But this is not simple, as some parts like the suspension or the engine have complex requirements that affect the driver's posture and comfort and which cannot be modified without altering the vehicle's performance. Moreover, if a light and easy-to-handle single-seater racing car is wanted, the solution passes through designing a very compact vehicle, which may conflict with the best ergonomics practices.

Although of enormous usefulness, a driving position design based on Digital Human Modelling (DHM) software is not sufficient (Hunn, 1998; Coutu, 2003; Chaffin, 2001), as this only evaluates static aspects like visibility or reach. So, this has to be supplemented with an empirical study on a real population group to satisfy the dynamic criteria, which are partly subjective and need a person's evaluation. Moreover, the main ergonomics parameters, like the position of the pedals, need to be meticulously adjusted to every driver. It is also usual to have a seat for every driver, made-to-measure to his size, and for which, quite often his own body is used to make the mould.

3 The Formula SAE competition

In 1982, engineers from Ford, DaimlerChrysler and General Motors, all members of the SAE, Society of Automotive Engineers, of the USA, being aware of how little newly graduated engineers were trained for work in automotive companies, designed a competition for universities throughout the world, which involved conceiving, designing and constructing a single seat formula-type vehicle and competing with it (Figure 2). This competition was called Formula SAE (Formula SAE Rules, 2009).

Figure 2 Single-seaters taking part in the formula SAE

It was thought that this challenge would serve to increase the skills profile of engineering students, forcing them to work as part of a team with high levels of communication, responsibility and motivation, applying knowledge acquired during their degree.

In order for projects to be uniform and provide equal opportunities in the competition, the SAE sets strict standards as the designing and manufacturing of different vehicle parts, in addition to stringent safety regulations. Most of these regulations are based on those imposed by the International Automobile Federation, the FIA, for other competitions. In spite of this, students are left with a considerable autonomy and capacity for innovation, as can be seen in the differences in the models from each university.

Every university must present a project as if it was dealing with a company manufacturing 1000 vehicles a year for an amateur public competing at weekends, and at a cost of under 25,000$ per vehicle.

The main condition refers to vehicle power, which is limited by engine capacity (600 cm^3 maximum) and by a limited air intake.

Other restrictions refer to vehicle size (1.520 mm minimum wheelbase, and a minimum 9 m slalom track pass), which means the vehicles are around 2700–3000 mm long. There is also an exhaustive check of the materials of which the chassis is built, and close attention is paid to safety and cockpit ergonomics.

Tests scored in the competition are divided into two categories: static and dynamic. In addition, there are other preliminary tests that do not score, but that need to be passed to reach the competition. Table 1 lists the tests together with a brief description of each.

Table 1 Description of the competition tests

Tests	*Points*	*Description*
Preliminary	*0*	*Pre-competition safety tests*
Technical inspection	–	General examination of the car by the judges
Inclination	–	The car is inclined at up to 60º to check stability and ensure there is no liquid leakage
Brakes	–	Simultaneous blocking of all four wheels after a brief acceleration
Noise	–	The vehicle is checked to ensure it emits less than 110 dB under certain acceleration conditions
Static	*325 in all*	*Presentations and oral defence before the judges of the technical solutions adopted*
Design	150	Technical defence of vehicle design and the solutions proposed
Presentation	75	Marketing presentation to convince the judges to choose their car as opposed to the others
Costs	100	Written report detailing the cost of each part and component of the unit built
Dynamics	*675 in all*	*Various on-track tests with the single-seater*
Acceleration	75	Cover 75 m in a straight run in the shortest possible time
Skidpad	50	Manoeuvrability test drive round a 9 m circle in both directions
Sprint	150	Fast lap of the circuit
Endurance	350	Overall vehicle performance and reliability during 22 laps of a circuit
Fuel	50	Minimum consumption in the endurance test
Total	*1000*	

As can be seen, this is an authentic engineering competition that evaluates not only vehicle speed and performance but also the project and the finished product. The students are the stars in this competition. They have to organise themselves, find the resources needed, manage project time, costs, etc., and all under the supervision of the advisory teachers and the 'Faculty Adviser'. The students must design and make the parts with their own hands (the fewer parts purchased the better), and four of them must finally drive the car.

What is new about this project, apart from it being a new, innovative educational methodology where the vehicle is simply the means to get the best possible training, is the challenge posed to the students by having to take on and participate in an entire vehicle development life cycle. This can only be achieved by forming a strong working team, promoting active participation, the assumption of responsibilities, decision making and involvement in reaching a common objective. In exchange, the student gets the satisfaction of being able to take the vehicle built by his/her own hard work to an actual competition.

Currently, more than 250 universities throughout the world take part each year in the Formula SAE. For this, it has been necessary to extend the competitions to other countries, like England, where it is called Formula Student, Australia, etc., as well as the original in Michigan. Overall, this is an important source of new professionals to set the foundations for a successful future career in the automotive industry.

4 Practical case: a Formula SAE cockpit design

When INSIA decided to set up the UPMracing team to take part in the Formula Student, it had experience in designing driving seats for vehicles and coaches (García et al., 2006), but a project design for a single-seater had never been taken on. For this reason, it was impossible to transmit any ad-hoc knowledge to students to help them with their work.

Apart from the competition constraints themselves, what is also highly appreciated is that design is carried out with the idea that the majority of people will be able to drive the car or the fact that regulations demand it be driven by several drivers in each of the tests; there were also other constraints specific to the UPMracing team. To be precise, the cockpit had to be designed without any prior knowledge as to who would eventually be the drivers as they would be chosen after the single-seater was finished, from among the students who had worked hard to build it, which meant the chance of being chosen would prove to be an incentive.

This considerably complicated the design process and was a reason for an ergonomic study of the vehicle to be made to analyse the physical constitution of the team members. The final objective set as a requirement was for any person who had between a 5% percentile female stature and a 95% percentile male stature, both North American standards, to be able to fit in the single-seater while meeting the 6 principles stated previously.

The intrinsic complexity of designing a cockpit for a single-seater competition car with all these requisites is accompanied by a lack of practical literature (SAE Standards, 1987) since most competition teams keep their research secret. This means that a team starting to design a single-seater must start out from square one conducting trials, taking measurements and making tests; such was the case of UPMracing.

Before beginning the design, an analysis was made of the objectives that it was hoped to meet. Some general sketches were made to bring the comfort posture sought closer to the other vehicle components. It is recommended (SAE Standards, 1987; Porter and Gyi, 1998; Hanson et al., 2006; Kyung et al., 2008) certain distances in the angles of the joints to obtain a good driving position in a car. Although in our case it was necessary to make the seat-back more reclined and the feet more raised than in a standard car, we started out from the data provided on comfortable joint angles.

In addition to the preliminary sketches (Figure 3), some life-size mock-ups were made so that the driver and the main vehicle systems could be put in place (Figure 4).

Figure 3 Preliminary design sketch of the cockpit

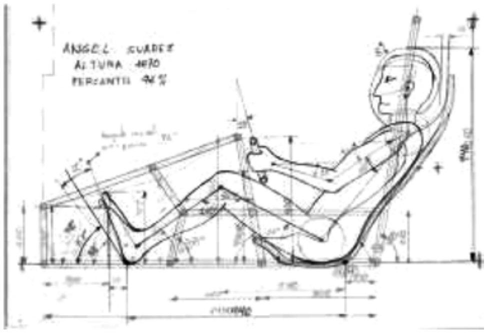


Figure 4 Test with sheets of cardboard

4.1 Methodology

The methodology carried out for the design and manufacture of cockpit and seat was as follows:

- Collection of the main 15 anthropometric measurements from the 22 team members. These measures were used to assure that all of them were inside the 5% female–95% male range, and if not, to increase this range.
- Development of a custom cockpit simulator regulated with several degrees of freedom.
- Analysis of the main parameters of the cockpit, like the seat, the position of driving elements, etc., by using the cockpit simulator with the team members, to define the best-scored driving comfort position.
- Design the chassis with CATIA V5 CAD software. For that, 95% male and 5% female North American percentile dummies have to be modelled. The main focus of these dummies is to produce iterative simulations of position in the cockpit components within the previous comfort ranges measured. The goal for this activity is to assess the ergonomics issues, including the operation capabilities, the visibility, etc. After the validation of main configuration, all other vehicle's components are

designed and placed on the model, like the suspension, the engine, the bodywork or the wheels.

- Manufacture of chassis and seat. Once the position of each component is set to meet all the requirements, the chassis is built and major components are assembled, such as pedals, steering wheel and shifter. The seat is built considering the space and position required by dummies. The framework for the external face of the mould is carried out in wood boards, and the internal face of the mould is made using the body of one of the possible drivers. Between the two faces of the mould, a bag with polyurethane foam is placed to define the desired shape of the seat. The final seat will be manufactured with fibre glass using the previous configured polyurethane foam piece as a mould.
- Finally, tests on vehicle have to be performed on track to verify that the design meets the requirements. This phase had been conducted using surveys from the four selected drivers.

Thus, as is usually done during the designing of human interfaces, it is necessary to balance the use of real anthropometric measures with virtual simulations, since CAD dummies' dimensions are not standard, and they need to be adjusted with actual data. Moreover, dummies cannot be deformed or adapted adequately to surfaces, as a human does when sitting on a seat. In addition, we need to be sure that the final design is adequate, since the dummy does not complain, either, it tells us where it hurts or what parts of its body feels any fatigue. Nonetheless, when designing a whole vehicle it is not possible to avoid the virtual phase, since it is very helpful on the designing and manufacturing of a complex system with many subsystems interacting with each other.

4.2 Anthropometric measurements

As it was not known a priori who the drivers would be, anthropometric measurements of the 22 team members were taken, with some very varied results. To do this, a measuring table was used (Figures 5–7) that had a series of graduated scales so that the most representative measurements could be taken in a seated position.

Figure 5 Anthropometric measuring table

Figure 6 Measuring elbow–hand length

Figure 7 Measuring chest perimeter

Although Hanson et al. (2006) defines nine (9) anthropometric characteristics in his methodology to define a preferred driving position, in our study we decided to measure another 6 anthropometric variables of every individual, what turned out enough to characterise a computer model (dummy) with the anthropometry of the person measured:

1	Height	6	Sitting height	11	Hip width
2	Weight	7	Field of vision when seated	12	Shoulder width
3	Buttock–knee length	8	Shoulder–elbow length	13	Waist perimeter
4	Knee–heel length	9	Elbow–hand length (including hand)	14	Hip perimeter
5	Sitting shoulder height	10	Foot length	15	Chest perimeter

Table 2 shows a summary with the mean, the standard deviation and the minimum and maximum of the 9 (Hanson et al., 2006) most relevant measurements.

Table 2 Anthropometric measurements of the group evaluated

$N = 22$	*Height* (mm)	*Weight* (kg)	*Sitting height*	*Buttock-knee length*	*Knee-heel length*	*Shoulder width*	*Shoulder-elbow length*	*Elbow-hand length*	*Hip width*
Mean	1751.36	71.45	905.23	494.64	486.82	413.18	350.45	477.04	366.14
Standard deviation	82.13	11.01	41.73	22.08	31.22	27.32	23.7	827.76	20.47
Minimum	1570	45	825	457	420	350	290	405	320
Maximum	1910	88	980	550	540	455	380	520	400

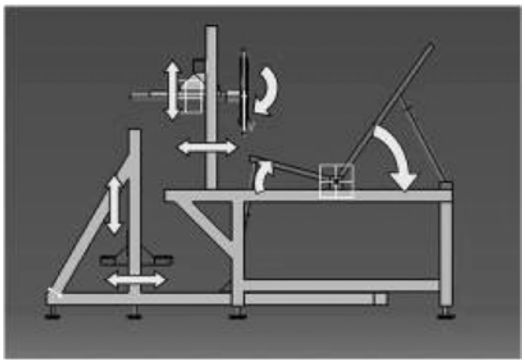
One of the most critical measurements is hip width, basic for the designing of a seat that needs to adjust well to the body to hold it firmly in place against lateral forces. Head height when seated is also important for positioning the rollover protective arc and the headrests.

4.3 Tests with the cockpit simulator

Having taken the anthropometric measurements of the potential drivers, tests were then performed to evaluate dynamic criteria and the driving position. So that each individual could freely choose the most comfortable posture for them, a simulator with an adjustable cockpit for the single-seater was designed with every possible degree of freedom (Figure 8). The driver could choose the following parameters:

- height and length of the pedals (brake, accelerator and clutch)
- height length and inclination of the steering wheel
- inclination of the seat and its back
- height and length of the gear lever and its distance from the steering wheel.

Figure 8 Side view of the ergonomics simulator with all its degrees of freedom



The test procedure was as follows: all drivers received instructions of how to perform the test. Then, every driver was given 15 min during which each of the adjustable parameters was gradually changed so that the most comfortable could be chosen. Afterwards, they were subjected to a 30 min test where driving had to be simulated following a series of simple instructions (braking, gear changes, turns, etc.) that the driver read and performed (Figure 9). The list contained 20 operations typical of a competition circuit that were repeated in a loop until the half hour test time was up. A computer screen with two simulations was also added to the simulator: one active, consisting of a car-driving video game, and another passive one with a route run by a single-seater on a racetrack with typical competition features. In both cases, they were asked to practise for different lengths of time.

During the tests, the required measurements were taken: those that characterise the driver's driving position and those related to cockpit size (Figure 10).

Figure 9 Test in the ergonomics simulator

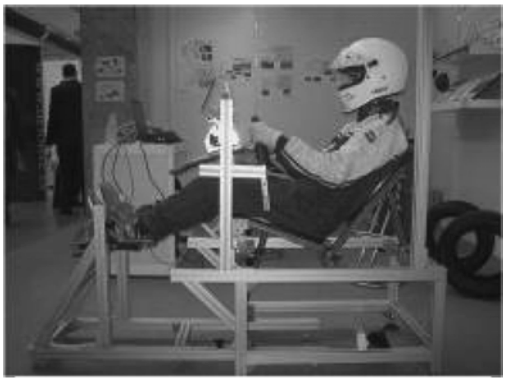


Figure 10 Taking one of the posture measurements

To be specific, the angles in 6 joints were measured (Table 3) following the techniques described by Porter and Gyi (1998) to define the driving position adopted by each driver. The mean was calculated, the standard deviation and the minimum and maximum of the data obtained. These variables define the driving position adopted for each driver.

Table 3 Measurement of the angles of the driving position

$N = 22$	*Heel angle*	*Knee angle*	*Trunk-thigh angle*	*Trunk-ARM angle*	*Elbow angle*	*Neck inclination*
Mean	80.17º	135.67º	112.5º	18.67º	120.33º	45.16º
Standard deviation	7.25º	7.73º	5.35º	5.95º	9.6º	5.23º
Minimum	69º	124º	107º	13º	110º	35º
Maximum	91º	146º	122º	30º	136º	50º
Rebiffe (Theoretical)	90–110º	95–135º	95–120º	10–45º	80–120º	20–30º

In the last row of Table 3, the theoretical intervals studied by Rebiffe (1969) for adopting a comfortable driving position in a car have been added. The differences between this posture and that adopted for the single-seater can be appreciated. The neck inclination and the heel angle fall outside those intervals, which leads us to suspect these will be the zones that most suffer fatigue.

In addition to the above, also measured was the distance between both knees, the distance between elbows, etc. Given that the single-seater to be designed would have a manual gear change not a power-assisted one, it was essential to measure the distance and angle of the elbow when operating the gear change in neutral so that enough space for a comfortable gear change could be provided.

Having completed the test, each driver was given a questionnaire where they were asked to answer a series of questions (Kyung et al., 2008) referring to driver posture comfort and fatigue in the body, as critically as they possibly could. The following conclusions were reached:

- The clutch foot is in permanent tension, since while it is not operating the pedal it is suspended in the air. This resulted in fatigue for most of the drivers polled. To solve this, fitting a footrest or fourth pedal attached to the pedal set was proposed (it cannot be attached to the chassis since the pedals need to be adjustable in length).
- Some drivers suffered neck pain in the lower vertebrae or in the shoulder (Figure 11). This is because the driving position requires the neck to be inclined in excess and the weight of the helmet also has an influence.
- The accelerator pedal can be pressed down a long way compared with the brake pedal (Figure 12). This causes the foot to make considerable movements (it is not enough to move the heel) to go from full acceleration to braking. This caused some drivers to have a feeling of fatigue in the right foot. One of the drivers polled could find no comfortable posture in spite of changing his leg position numerous times. Two possible solutions are to reduce the length of the accelerator path, which in turn causes the engine load control to react less precisely. The second is to move the accelerator forward compared with the brake, which was the solution adopted. This also meant that the engine revolutions could be maintained during braking thereby achieving an improvement in the vehicle's longitudinal accelerations.

Figure 11 Uncomfortable neck posture

Figure 12 Pedal set design fault

4.4 Defining the comfortable posture

The posture has to allow the majority of population group (5–95% percentiles) to comfortably fit into the single-seater. To define a comfortable posture, Rebiffe's (1969) criteria were used as first reference, and with the simulation results exposed on Table 3 in addition to the conclusions of the questionnaire, a comfort posture was defined (Table 4). The heel and neck angels were moved around 5º from the mean value due to the presence of fatigue detected on the questionnaire.

Table 4 Final posture angles

Heel angle	*Knee angle*	*Trunk-thigh angle*	*Trunk-arm angle*	*Elbow angle*	*Neck inclination*
85º	135º	112º	19º	120º	40º

The measurements taken to position the steering wheel, the pedals, the seat, the headrest and the gear change in respect of an origin of coordinates located at the point of intersection between the seat and the seat-back are as follows (Table 5):

Table 5 Measurements for the cockpit design

N = 22	*Heel length*	*Steering wheel length*	*Steering wheel height*	*Seat-back inclination*	*Knees height*	*Headrests height*
Mean	960.83	316.67	478.33	51.66	365.83	737.5
Standard deviation	48.31	41.91	28.75	2.64	36.66	61.21
Minimum	895	280	435	48,5	315	665
Maximum	1015	390	510	5	405	825

Deciding at what angle the seat-back should be reclined was a major decision. Designing an adjustable seat would make no sense in this kind of vehicle as it would greatly complicate its manufacture and the positioning of the safety harness and the rollover protective arc, which, it should not be forgotten, are governed by regulations. The final seat-back inclination is 52º (Table 5).

The headrest on the single-seater is also fixed, but it is long enough to take in the full-required range (665–825mm).

Regarding knee–heel length, which decides where to position the pedals, a significant difference was noted between a person with short legs and another with long legs. Box pedals that are adjustable in longitudinal length are, therefore, required.

The final decision was the position of the steering wheel. While an adjustable height steering wheel would not be very difficult to design, its range of variation would be very small. This is because regulations state that the topmost point of the steering wheel cannot project from the chassis, and if its height was lowered, it would be in contact with the driver's knees due to the driving position. The steering wheel height was, therefore, fixed at 490 mm. This figure is above the mean so that large drivers do not knock their knees against the steering wheel when turning it.

So, of the three adjustable parameters (pedals, steering wheel and seat), the steering wheel is the least critical. By adjusting the length of the pedals and with an appropriate seat design, the cockpit can be adapted to the different measurements of the population studied.

4.5 Sizing the chassis design

The adjustment intervals of each parameter and the final measurements were analysed with the aid of the ergonomics module of the CAD CATIA V5 program, called Ergonomics Design & Analysis. With this module, a dummy can be edited with the dimensions and driving position (Figures 13 and 14) of any individual evaluated.

Figure 13 Anthropometry of a 95% percentile dummy in CATIA v5

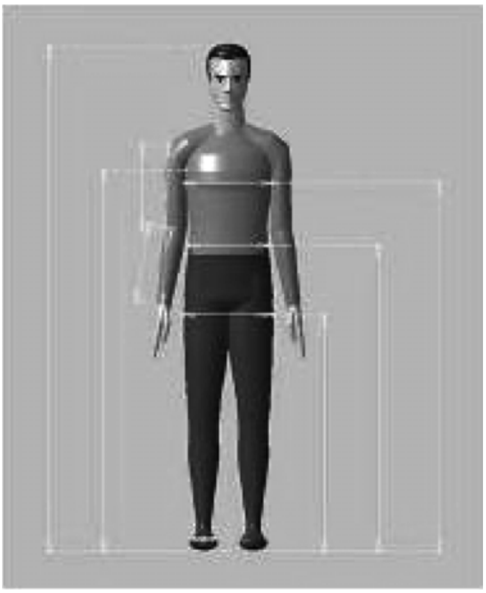
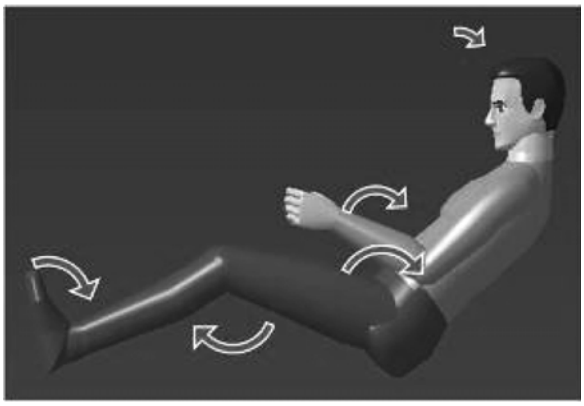
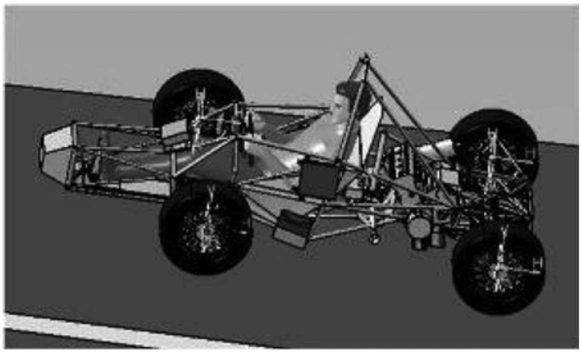


Figure 14 95% percentile dummy in the comfort posture in CATIA v5



When we had modelled the 95% percentile dummy in its driving position, the chassis could be designed around its body (Figure 15), assembling it together with the other components that had been previously modelled.

Figure 15 Chassis and other single-seater components with a 95% driver percentile in CATIA v5



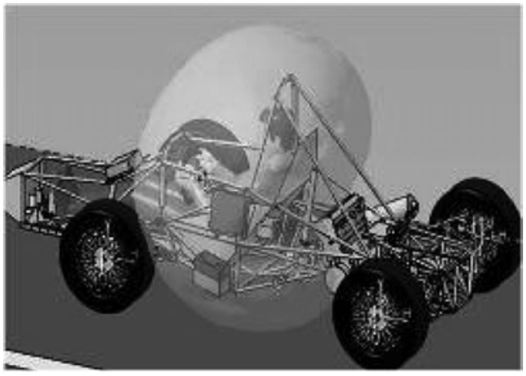
4.6 Meeting specifications

When the main components had been modelled and assembled into a whole, the time had come to check they met both competition and team specifications. Among the latter are static criteria that can be evaluated with the CATIA v5 Ergonomics module.

On the one hand, the model analyses the visibility of any driver, for example, the 5th percentile female (Figure 16) as it is important for the instrument panel and a large part of the roadway to be in direct view. It also analyses the distance to reach the controls and again the 5th percentile female is an example of a critical case. The yellow sphere represents the distance reached by the left hand of a 5th percentile female without the back becoming separated from the seat (see Figure 17).

Figure 16 5% female percentile field of vision

Figure 17 Sphere reached by a 95% percentile



However, results obtained by DHM software are not always reliable due to the difficulty of modelling the human body, that as it was stated in the methodology, the dummy cannot deform or adapt to a surface. When the chassis design was completed, a scale 1 : 1 model was built to ensure the design was right. The materials chosen for this model were PVC tubes (Figure 18) joined with glue as this is a fast, cheap way to build.

Figure 18 Model of the PVC chassis tested by a 98% percentile driver

4.7 Constructing the chassis and seat

Having made all these checks, construction of the cockpit began with welded carbon steel tubes in line with competition specifications for materials and measurement (Figure 19).

Figure 19 End result of the single-seater cockpit with all the controls

Without any doubt, the most difficult component to make was the seat (SAE Standards, 1987), since this had to take up as little space as possible, be very light and at the same time tough. The material selected was glass-fibre-reinforced polyester, as it is a cheap and easy-to-use technology that comprised all the requirements. Despite having a 3D model obtained from the dummy's back fitted in 3D to design and construct the seat, it was decided to do it by hand using the back of one of the drivers.

The two main parameters that define the seat geometry are the sitting height and the hip width, and the seat manufactured was adjusted to the median of the possible drivers that matched with 80th percentile sitting height measurement and a 70th percentile hip width.

The back of the driver chosen was used to make the seat mould in the following way: first, a cockpit was made in medium-density fibre board and the driver placed inside in the posture to be adapted to the single-seater (Figure 20). During this procedure, the driver must be well protected so that there is no risk of intoxication and the seat-back angle required checked together with the correct posture for the spinal column.

Figure 20 Model driver of the seat with the comfort posture in the wooden cockpit

Using a polyol-isocyanate, which gives polyurethane, all the gaps between the body and the cockpit were filled (Figure 21). The result was a preliminary seat mould, which only needed a good finish.

Figure 21 Polyurethane mould obtained from the driver's back and buttocks

Errors were subsequently corrected and any cracks found were filled. To harden the mould plaster, bandage strips were applied to the whole surface of the seat, and when it was all-hard and dry it was lightly sanded. Thus, the mould was ready for the application of layers of fibre glass (Figure 22). Even though the whole seat was fairly rigid, fewer layers of fibre glass were applied to the part of the seat that held the driver's hip and thighs so that it would have the required flexibility.

Figure 22 Fibre glass seat on the mould

The final procedures to give it a finish consisted of separating the seat from the mould, cutting it to shape, trimming it, painting it, coating it with neoprene to give it a better appearance and then fitting it into the chassis (Figure 23).

Figure 23 Finished seat

Since the goodness of design made must be assessed in dynamic testing on track where the accelerations, vibrations and coordination in handling high-speed controls come into play, these validation tests were only carried out by the four drivers selected to participate in competition.

The four drivers were given a survey related to vehicle's ergonomics, which was divided into eight parts: pedals, steering wheel, shift levers, seat, instruments panel, chassis, headrest and inertial forces. The aim was to obtain open answers about driving position and seat comfort to improve actual and future single-seaters.

All of them reflected an absence of fatigue beyond what it was expected when driving a high physical demanding vehicle, what showed that the whole ergonomics was very satisfactory (Figure 24).

Figure 24 The single-seater at a race

5 Conclusions

As a main conclusion, it can be said the characteristics of driving a single-seater are different from those of a conventional car. In addition, the lack of a clear bibliography and accessible data based on ergonomic single-seater cockpit design led to the development of a methodology that was meticulously documented at every stage. The use of a measuring table, the creation of a cockpit simulator and the use of ergonomics software enabled the designers to satisfy vehicle ergonomic and functional requirements at the same time. The data recorded, ranging from the anthropometric measurements of the possible drivers to the angles of greatest comfort and driving efficiency, have served as a basis for designing new vehicles. The methodology was very well scored by the competition judges. In addition, no driver reported discomfort or driver fatigue. Future work will study the effects of vibrations transmitted from the road to the driver through the suspension, and the possibility of introducing absorbent and elastic materials in the seat clamps.

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