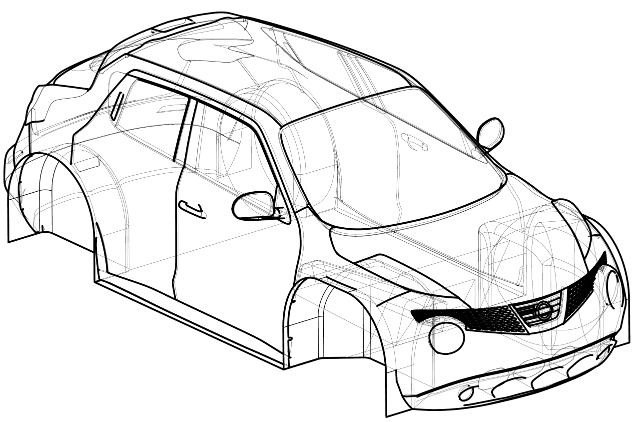
POLITECNICO DI TORINO

MSc Automotive Engineering

A.Y. 2023/24

Car Body Design

Project 1



Carlo Vittorio Colucci 329703

Riccardo Bressani 323665

Pierpaolo Placida 323197

Alessio Covetti 329876

Introduction

Among mechanical organs dealing with the vehicle front-end, wheel arch is one of the most sensitive. Proper wheel arch design and sizing must be carried out considering not only the geometrical dimensions of tyres and unsprung masses, but also the limit conditions of operation of the steering system, related to the manoeuvrability of the car. The initial and fundamental phase of the design process aims to obtain the maximum steering angles of the tyres, reached by passenger cars only during parking conditions. From these sizes, both a top and side view is carried out, considering furthermore the influence of standard load distributions on the suspension system. In the end, a whole wheel arch design is estimated, focusing on suspension deflection and ground clearance.

Due to the high dependence of design quotes on the vehicle relevant parameters, it has been taken into consideration a Nissan Juke model from 2011, a car that was always available during the project work and that has been possible to measure, both from the dimensions and weight point of view, thanks in particular to post-process software as Tracker and a weighing machine, available from a local mechanical workshop.

Method and results

Data acquisition

Most of relevant data and parameters of the selected vehicle have been taken from maintenance booklet datasheet. However, not all the necessary values were available, which is why more geometrical considerations have been adopted, especially for maximum steering angles. The employment of the workshop weighing machine provided not only the loads acting on the front and rear axle, which are necessary for the evaluation of the centre of gravity, but also the forces applied on the left side and right side of the vehicle. This information indicated that the frontal weight distribution is asymmetric, with the left side more loaded.

Concerning the tyres' size, for the considered vehicle model two rims dimensions were available. In order to properly design the wheel arch for the two possibilities, the largest rims have been considered. The following data have been directly extracted from datasheet:

- Wheelbase: $w = 2{,}53\ m$
- Front track: $t_f = 1{,}525\ m$
- Rear track: $t_r = 1{,}505\ m$
- Tire size: 215/55R17 94V
- Number of occupants: $passenger = 5$

- Minimum steering radius: $R_{min} = 5{,}5\ m$

The following data have been measured through weighing machine:

- Mass: $M = 1337{,}5\ kg$
- Front axle force: $F_f = 8231N$
- Rear axle force: $F_r = 4890N$
- Percentage weight distribution (front:rear): 62,7 : 37,3

Figure 1: Weighting operation for mass distribution measurement

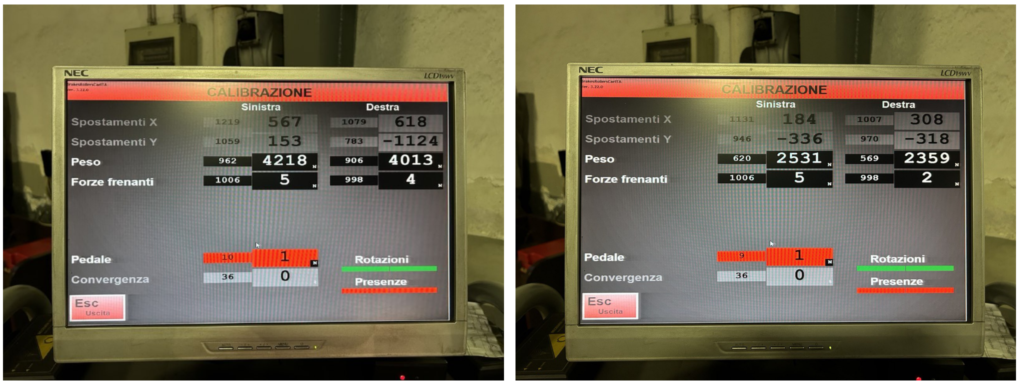


Figure 2: Front and rear axle measured forces

The dimensions related to the positions of the occupants have been obtained by processing a photo using the software Tracker taking as reference value the known wheelbase:

- Distance front axle front passenger hip point: $a_{P_1} = 1{,}392m$
- Distance front axle rear passenger hip point: $a_{P_2} = 2{,}064m$
- Distance front axle luggage: $a_L = 2{,}566m$

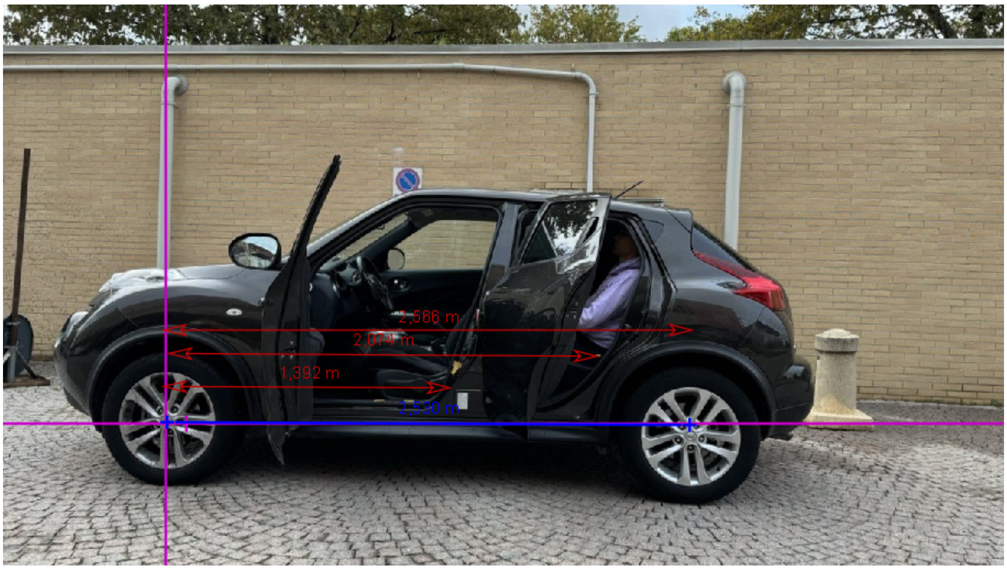


Figure 3: Passengers and luggage position measurement

Maximum wheels steering angles

The maximum steering angles are obtained under the hypothesis of Ackermann steering in the condition of minimum steering radius (provided by datasheet):

$$R_1 = -\frac{t_r}{2} + \sqrt{R_{min}^2 - w^2} = 4{,}13\ m$$

$$\delta_1 = arctan(\frac{w}{R_1 - \frac{t_r}{2}}) = 36{,}83°$$

$$\delta_2 = arctan(\frac{w}{R_1 + \frac{t_r}{2}}) = 27{,}39°$$

where δ_1 and δ_2 are the steering angles of the in the bend and out of the bend wheels respectively.

Design of the wheel arches - Top view

For the design of the wheel arches additional layers have been considered, accounting for the dirt accumulated on the tyre tread and the influence of the snow chains. An important remark is that the dirt layer has been represented through a thickness increase of 10 mm only in radial direction, while the snow chains presence has been considered through a 15 mm layer in both radial and lateral direction. The wheels considered for the wheel arch design have therefore the following dimensions:

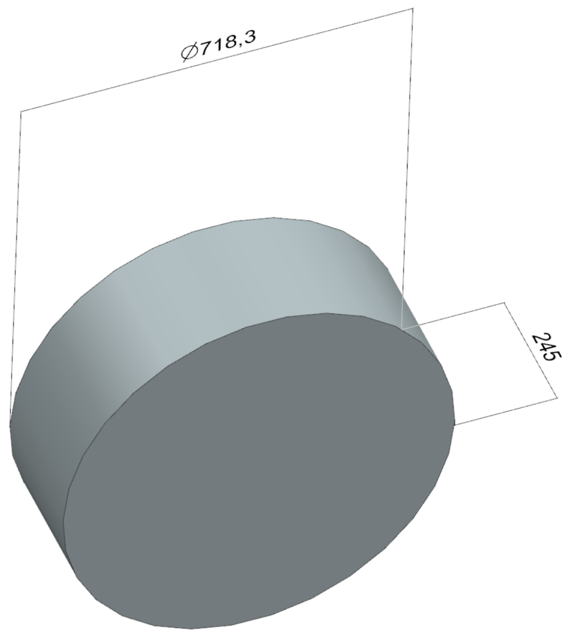


Figure 4: Wheel dimensions accounting for snow chains and dirt

Starting from the positions with respect to the car body footprint, the front wheels have been rotated by the two maximum calculated steering angles. Since the real steering axis is not known, it is assumed located on the internal face of the wheel, perpendicular to the ground on the contact point between the latter and the wheel. Once the positions of the steered wheels are obtained, the wheel arch is built with a polygon enclosing this envelope, with the internal wall parallel to the car longitudinal axis. To provide further clearance, an offset of 25 mm is taken from the minimum shape. The following sketch shows the results obtained through CAD; quotes of transversal dimensions are referred to the boundary lateral footprint of the vehicle.

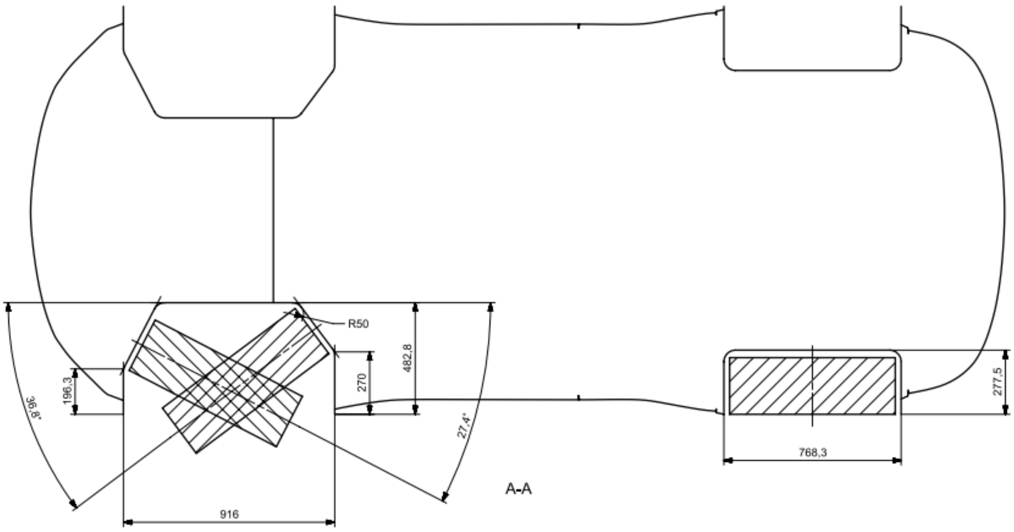


Figure 5: Wheel arches top view

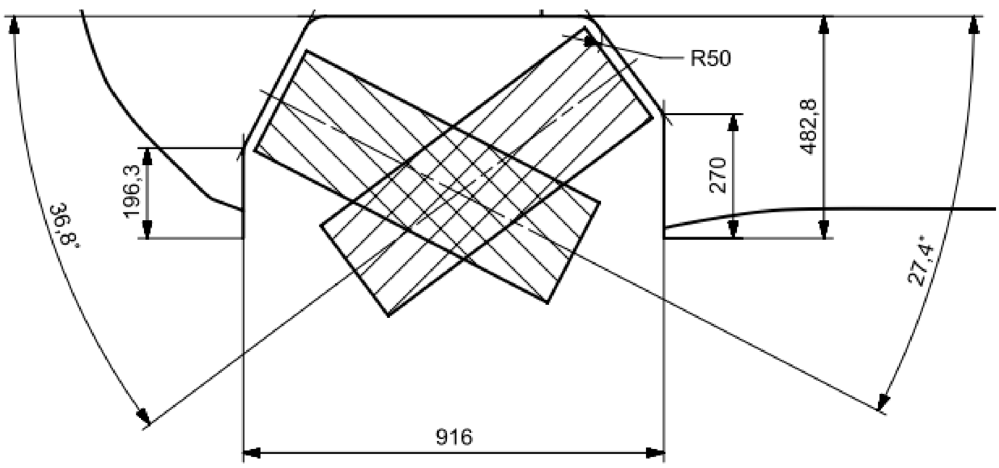


Figure 6: Front wheel arch top view

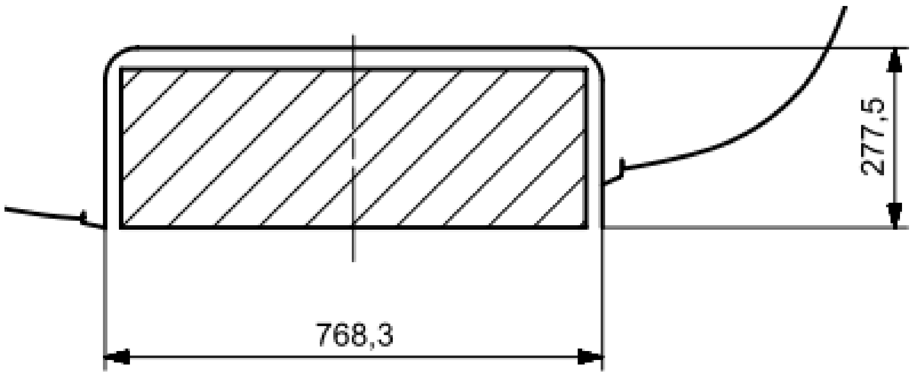


Figure 7: Rear wheel arch top view

Design of the wheel arches - Side view

Regarding the side view design, different standards of loads are taken into consideration. The standards, named from A to F, represent the conditions in which the car hosts from none to five passengers (70 kg), each one with a 10 kg luggage in the boot. From a simple equilibrium of moments the load variation on front (ΔF_F) and rear axle (ΔF_F) for each standard can be calculated:

$$\Delta F_{F_{1,2}} = F_P \cdot \frac{b_{P_{1,2}}}{w} - F_L \cdot \frac{b_L}{w}$$

$$\Delta F_{R_{1,2}} = F_P \cdot \frac{a_{P_{1,2}}}{w} + F_L \cdot \frac{a_L}{w}$$

where:
- $F_P = 70 \cdot g$ is the weight of each passenger;
- $b_{p_{1,2}} = w - a_{p_{1,2}}$ are the distances of the passengers' hip points from the rear axle;
- $F_L = 10 \cdot g$ is the weight of each luggage;
- $b_L = a_L - w$ is the distance of the luggage from rear axle;
- subscripts 1,2 refer to front or rear seat rows, therefore 1 is considered

for standards B and C while 2 for D,E,F.
The resulting loads are reported below:

Standard	A	B	C	D	E	F
Front force [N]	8231	8538	8846	8968	9091	9213
Rear force [N]	4890	5367	5845	6507	7169	7832

Table 1: Front and rear axle vertical loads in standards A-F

The load distribution in full load conditions (standard F) is found:

$$\frac{F_F}{F_F + F_R} \cdot 100 = 54\%$$

$$\frac{F_R}{F_F + F_R} \cdot 100 = 46\%$$

The vertical stiffness of the suspensions is estimated on front and rear axles with the loads calculated in standard F (5 passengers + luggage). Since the measured vertical loads are uneven between left and right side, it is assumed to use the highest ones for the calculations (left side). The estimation of the stiffness is performed on the basis of the desired resonance frequency according to the quarter car model; for human sensitivity considerations, a good choice is $f_n = 1{,}5Hz$. Since:

$$f_n = \frac{1}{2\pi} \cdot \sqrt{\frac{k_s}{m_s}}$$

It is obtained:

$$k_{s_{F,R}} = m_{s_{F,R}}(2 \cdot \pi \cdot f_n)^2$$

Considering $m_{s_F} = \frac{F_F}{g}$ and $m_{s_R} = \frac{F_R}{g}$ both considered in standard F, the stiffness are:

$$k_{s_F} = 42{,}64\ \frac{N}{mm}$$

$$k_{s_R} = 36{,}24\ \frac{N}{mm}$$

Once the loads in the different standards and the stiffness values are known, the suspension vertical deflections can be evaluated:

$$\Delta z_{F,R} = \frac{\Delta F_{F,R}}{k_{s_{F,R}}}$$

The results for the different standards are reported:

Standard	A	B	C	D	E	F
Front displacement [mm]	0	3,60	7,21	8,65	10,08	11,52
Rear displacement [mm]	0	6,58	13,17	22,31	31,45	40,60

Table 2: Front and rear axle vertical displacements in standards A-F

The side view dimensioning for the wheel arches is carried on starting from standard F and considering additional 40 mm to account for suspension vertical dynamics. From the limit wheel position the wheel arch is positioned with an additional vertical clearance of 25 mm. The following sketches shows the results obtained through CAD in the condition when the vehicle experiences the maximum downwards vertical travel (standard F + 40 mm travel):

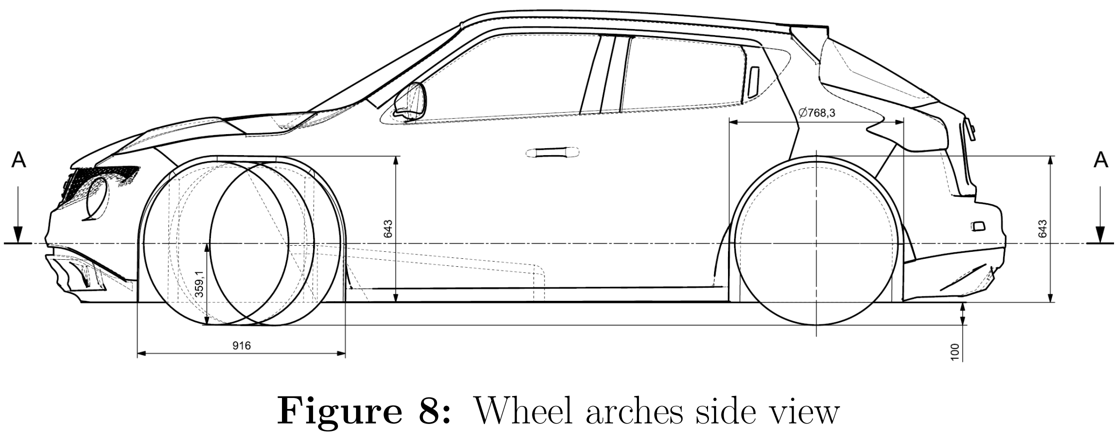


Figure 8: Wheel arches side view

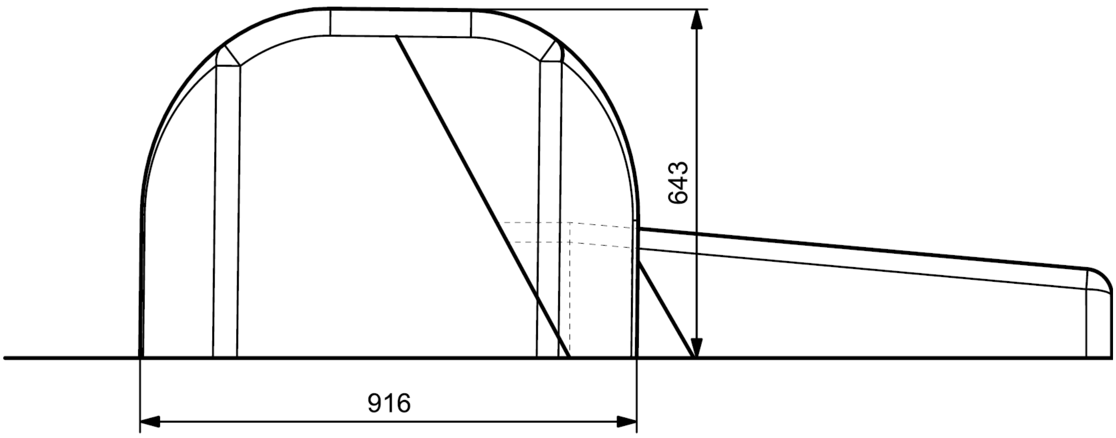


Figure 9: Front wheel arch side view

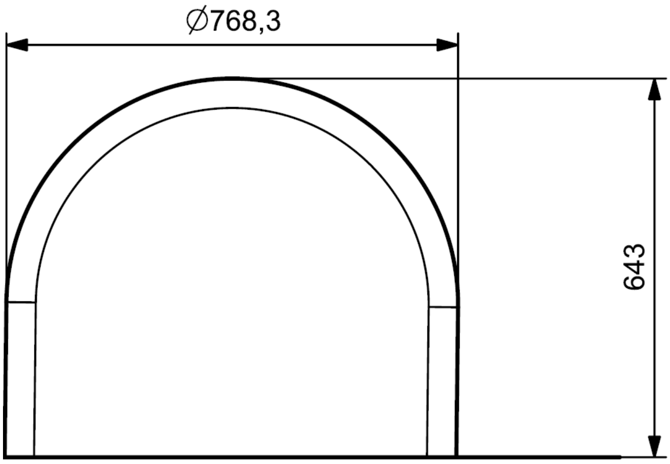


Figure 10: Rear wheel arch side view

The position of the vehicle underbody is determined starting from the assumption to guarantee, in the limit situation previously represented, a residual ground clearance of 100 mm, constant all over the length, to ensure safe operation. This assumption, considering the difference in vertical travel between front and rear suspensions, leads to a slight inclination of the vehicle floor at no load conditions. This angle can be easily computed as:

$$\alpha = arctan(\frac{\Delta z_R - \Delta z_F}{w}) = 0{,}66°$$

The ground clearance in standard A is therefore linearly varying along the length, as shown in the following sketch:

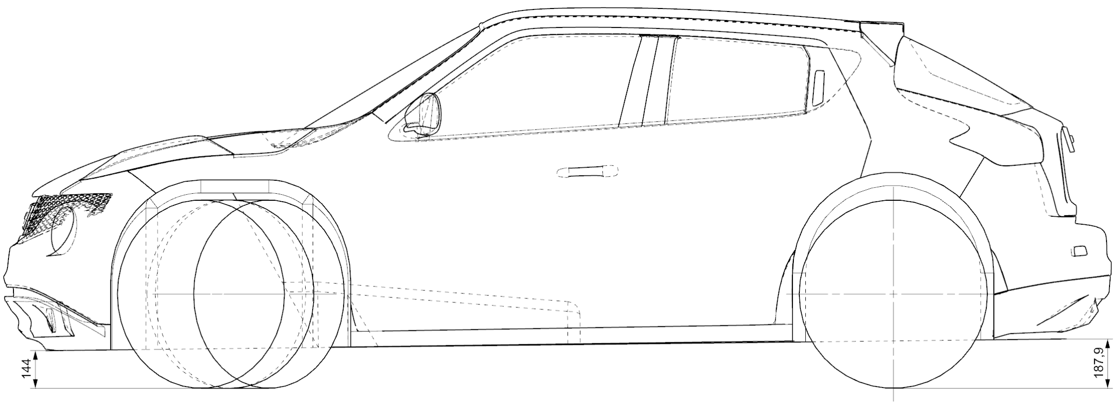


Figure 11: Ground clearance in standard A

Conclusions

The result of the project is a first design of the underbody of the considered vehicle, accounting for the dimensions of the wheel arches, as well as an indication of the presence of firewall, pedalboard and central tunnel. The body shape represented in the previous figures is meant to show the proportions between the obtained part and the real geometry and has been derived from a 3D model available online.

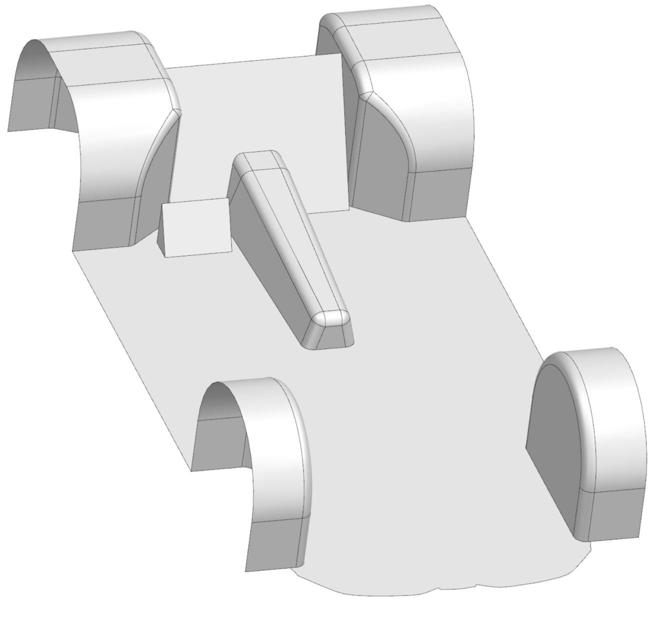


Figure 12: Underbody preliminary design

The comparison between the design of the wheel arches performed in this work and the real ones show a general overestimation of the required dimensions. This can be due to several factors:

- The real steering kinematics has not been accounted: choosing the steering axis externally with respect to the wheel is probably providing a bigger required volume with respect to the real one in maximum steering condition;

- The real dynamics of the suspension is unknown: the vertical displacements have been calculated only on the basis of the applied static loads, without considering the actual travel allowed by endstops designed be the manufacturer;

- The assumptions made on the necessary clearance between the limit positions of the wheels and the wheel arches are probably further overestimating the required space: such conditions are clearly already representing a worse case, so a smaller clearance from these situations can be chosen.