ANNEX

A.1. Aerodynamic concepts

To know the aerodynamic performance of a race car could be a bit difficult in the first instance. In order to determinate this, with the maximum objectivity possible, we are going to introduce some parameters that are frequently used in the motorsport industry.

Drag coefficient:

It is a dimensionless parameter that is used to quantify the resistance of an object in a fluid stream. The drag coefficient is associated with a particular surface area.

The aerodynamic resistance is divided in two groups, depending of the causes that generate it. Drag from viscous origin and drag from potential origin. With respect to the drag with viscous origin we can divide it in two categories. Skin friction and form drag. Both have greater influence on the overall drag.

The drag coefficient is defined as:

$$C_d = \frac{2F_d}{\rho v^2 A}$$

Where:

- F_d is the drag force, which is by definition the force component in the direction of the flow velocity.
- ρ is the density of the fluid.
- v is the relative speed with the fluid.
- *A is the frontal or plan area.*

The drag equation is a formula used to calculate the force of drag experienced by an object due to movement through a fully enclosing fluid. The formula is accurate only under certain conditions: the objects must have a blunt form factor and the fluid must have a large enough Reynolds number to produce turbulence behind the object.

$$F_d = \frac{1}{2}\rho v^2 C_d A$$

Lift coefficient:

It is a dimensionless parameter that relates the vertical force generated by a body with the dynamic pressure and a characteristic area of that body.

$$C_l = \frac{2F_l}{\rho v^2 A}$$

Where

- L is the lift force

In terms of the race car engineering is necessary reducing this force (negative values) in order to have a more powerful car. In contrast, production cars normally have positive lift coefficients, because the general shape of the bodyworks (with wing form) assists a low pressure upon the car. But this is a desired effect because reduce the total weight on the tires and as a consequence the rolling resistance is decreased.

Centre of pressure:

The centre of pressure is the point where the total aerodynamic force acts, causing a force but not a moment about this point. This is an issue to consider at the time of characterize the dynamic behaviour of the car.

The centre of pressure is defined as the integral of the pressure on a surface along a direction, divided by total pressure in this surface.

$$CoP_x = \frac{\int x \cdot P(x)\, dx}{\int P(x)\, dx}$$

$$CoP_y = \frac{\int y \cdot Py\, dx}{\int P(y)\, dx}$$

$$CoP_z = \frac{\int z \cdot P(z)\, dx}{\int P(z)\, dx}$$

Aerodynamic Efficiency:

The aerodynamic efficiency is one of the parameters to know how effective a car is. In aerodynamics terms, obviously. Also it is used to characterize the performance of an airfoil.

Is defined like the relation between the lift and drag forces.

$$\eta_A = \frac{F_d}{F_l}$$

Coefficient of pressure:

The difference between the local static pressure at any point in a flow and the static pressure in the free stream depends directly on the dynamic pressure of the free stream. Therefore, the ratio

$$\frac{local\ pressure - free\ stream\ pressure}{free\ stream\ dynamic\ pressure}$$

Remain constant at all speeds. This ratios is known as the pressure coefficient C_p

In some situations the coefficient of pressure in a body is independent of body size. As a consequence, a model can be tested in a wind tunnel to obtain the C_p at necessary points. These pressure ratios may be used to estimate the fluid pressure at these critical points in the scale prototype.

$$Cp = \frac{p - p_\infty}{\frac{1}{2}\rho_\infty V_\infty^2}$$

Where

- p is the static pressure in the checked point.

- p_∞ is the reference pressure or free stream pressure.
- ρ_∞ is the flow density.
- V_∞ is the free stream velocity.

Boundary layer

When the air flows along a body, this tends to coalesce to the surface. That occurs because the air is a viscous fluid, therefore the air layer which is contacting with the profile is fully attached and his velocity is zero in respect to the profile. According the flow is separating from the surface his speed is increasing up to the free stream velocity. This zone, where the flow is increasing his speed is known as boundary layer.

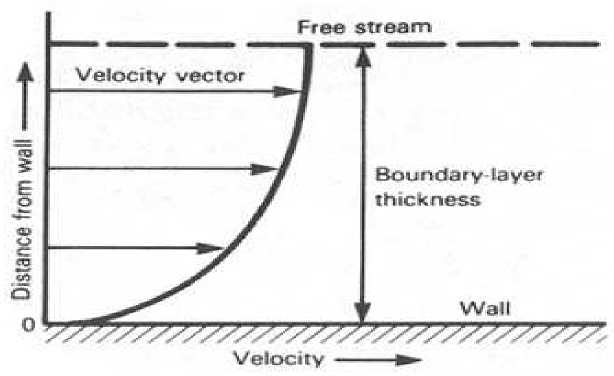

Image 38. Boundary layer speed profile

Likewise the flow can be laminar or turbulent, depending of various factors, but highly conditioned by the Reynolds number. In the turbulent regimen, the flow has a chaotic movement, unorganized and with an intensive mix between different layers. Otherwise the laminar flow is more constant and there is no mixing between different layers. The viscosity of the fluid has an important role regarding to the laminar or turbulent flow. Normally a flow is laminar, when the external perturbations to the fluid can be absorbed by the viscous effects, this perturbations do not affect to the normal regimen of the fluid and the “layers” can flow organized. By contrast, if the perturbations cannot be stabilized, the flow will enter in a chaotic state of movement.

The flow tends to be turbulent for high numbers of Reynolds, or laminar for lower numbers. Both conditioned by the stream velocity and its viscosity.

$$Re = \frac{\rho \cdot V \cdot L}{\mu}$$

Where

- ρ is the density of the fluid.
- V is the fluid speed.
- L is a characteristic dimension.
- μ is the viscosity of the fluid.

According with the Reynolds number, it is logical to think that if the "characteristic length$L$" grows, it is possible to pass from the laminar flow to turbulent in the same body by the effect of the viscous forces. This effect can be showed in the following picture.

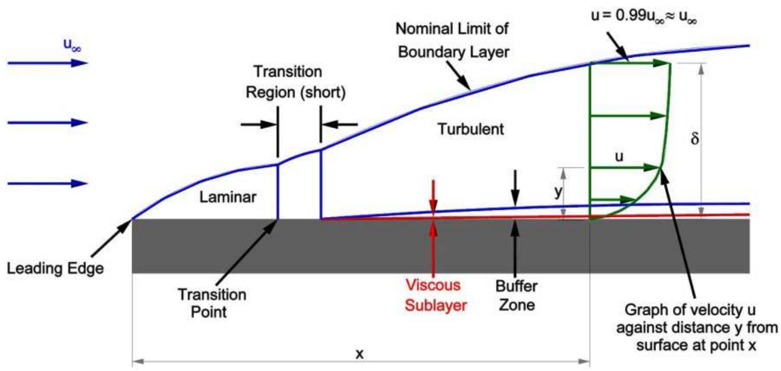

Image 39. Boundary layer development [30]

The boundary layer is laminar at the beginning of the shape, and is growing progressively. Then there is a transition region before reaching the zone in which the flow is completely turbulent, with a coarsening of the boundary layer.

Experimental methods have demonstrated that the turbulent flow is reaching for values of Reynolds about $5{\cdot}10^5$.

Is also important, at the time of predict the boundary layer detachment, the profile shape. If the shape is convergent the deceleration of the flow because of the viscous effects can be compensated by the acceleration that the flow suffers by the shape of the profile. By contrast if the shape is divergent, the pressure grows in the same direction that the stream and an adverse gradient of pressure is created. This causes the boundary layer can detach from the shape.

A.2. Detailed views of the car

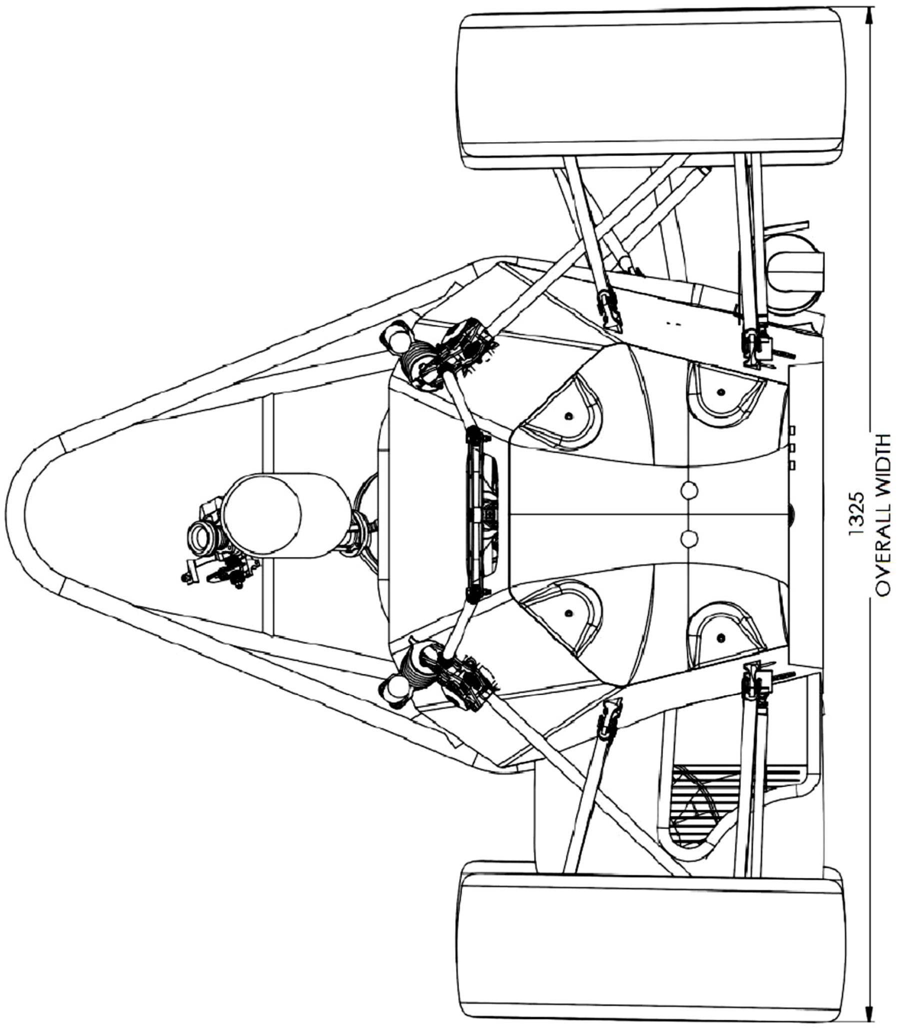

Image 40. Front view of the car.

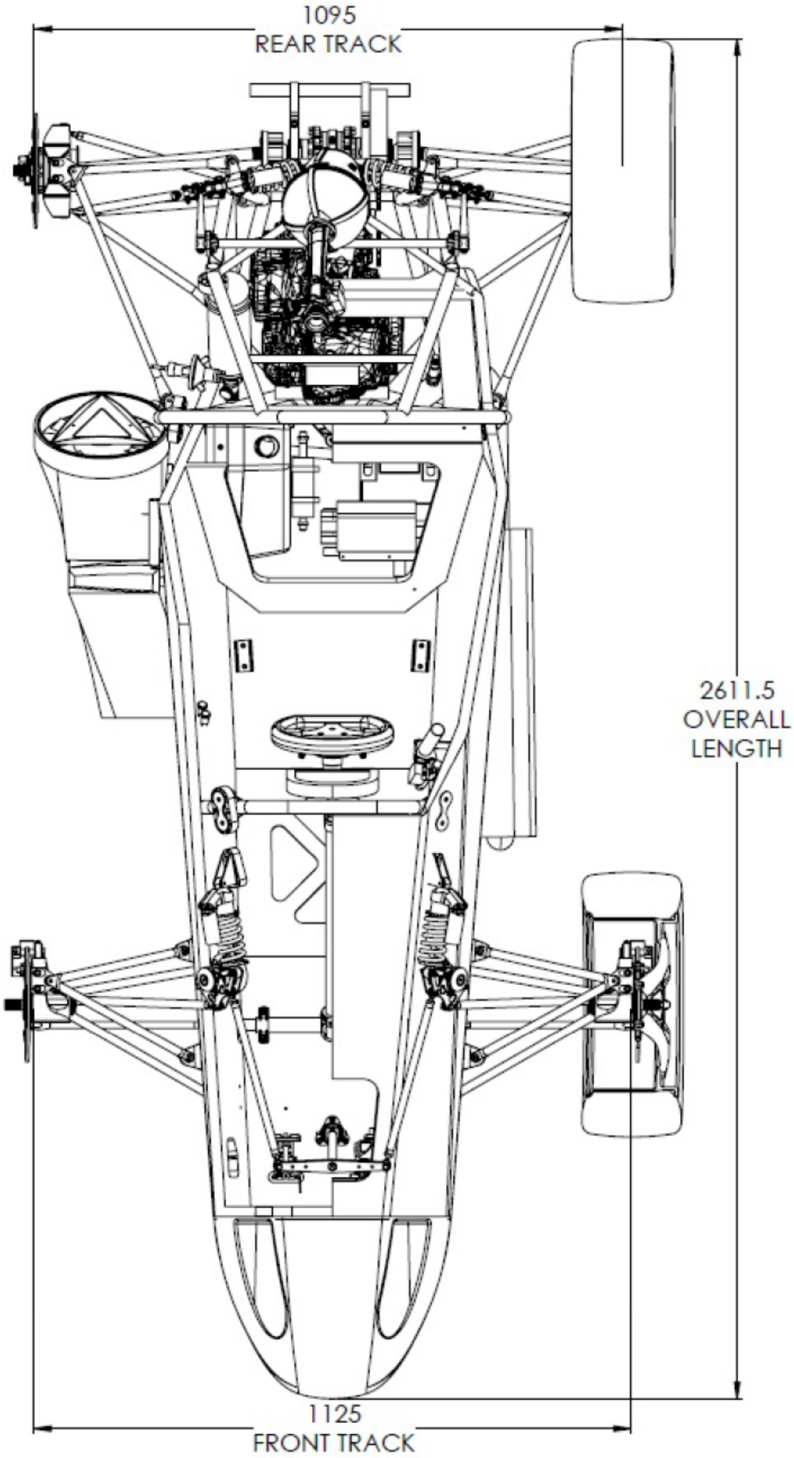

Image 41. Top view and section view

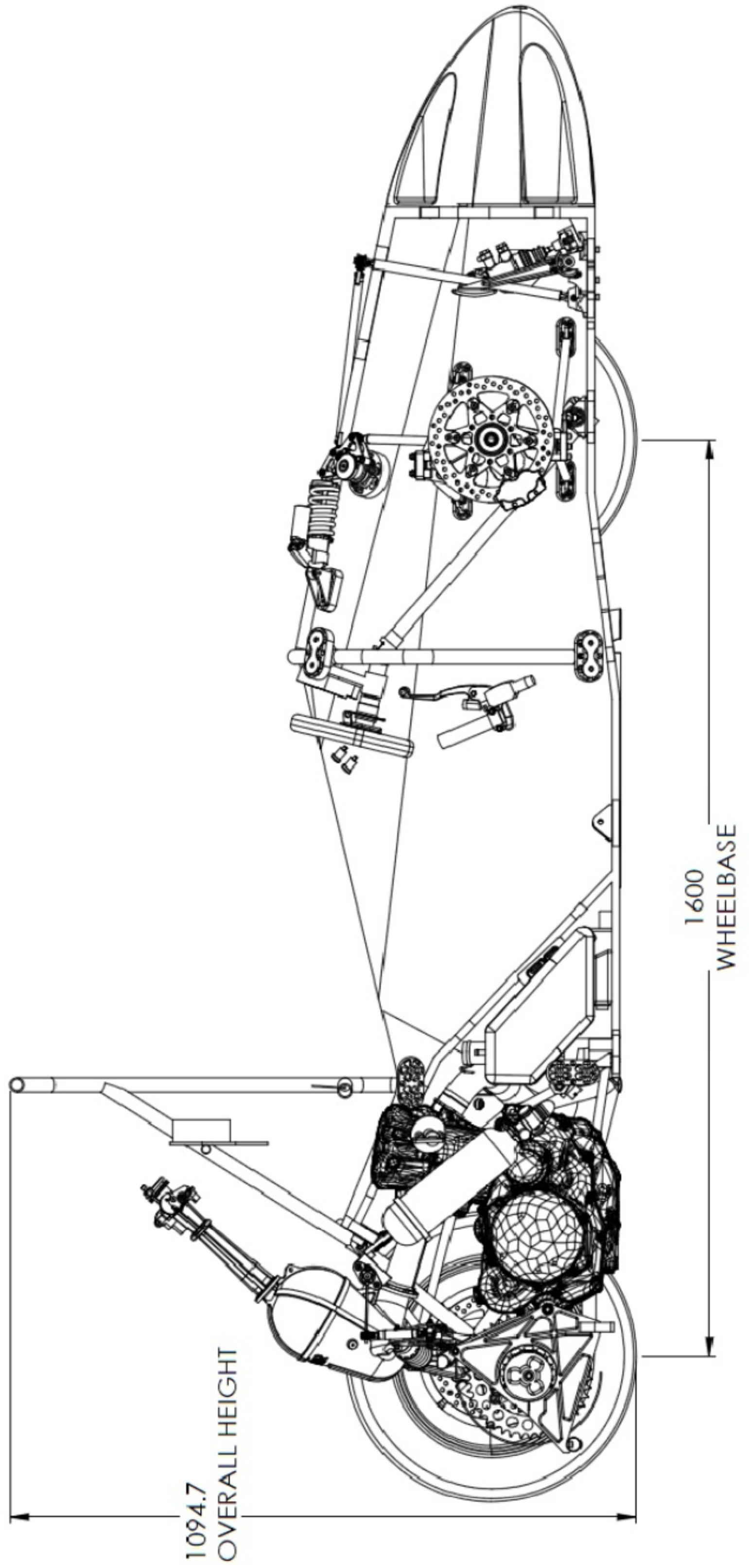

Image 42. Side view and section view.

A.3. Detailed views of the rear wings and the final design.

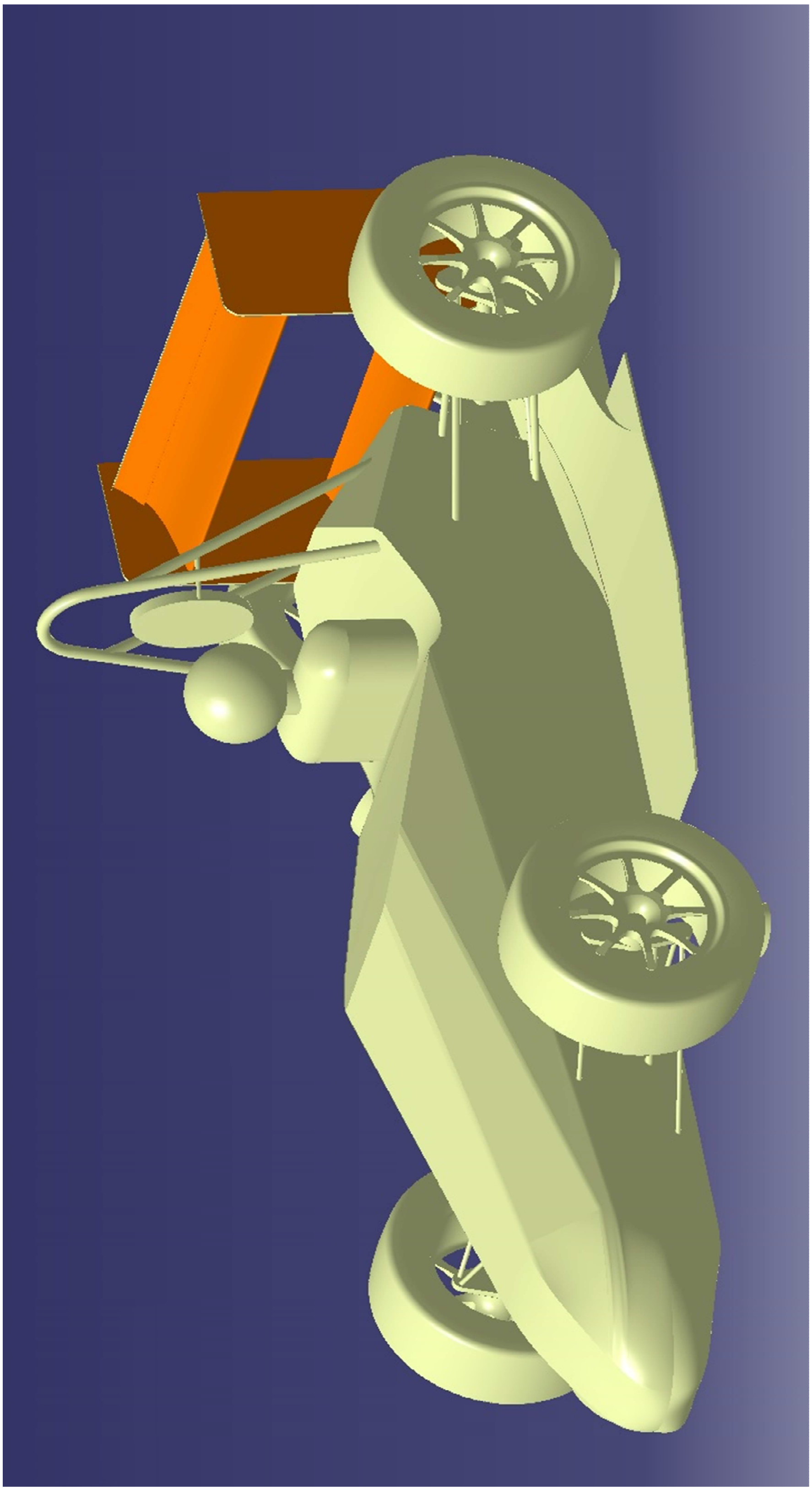

Image 43. First rear wing design

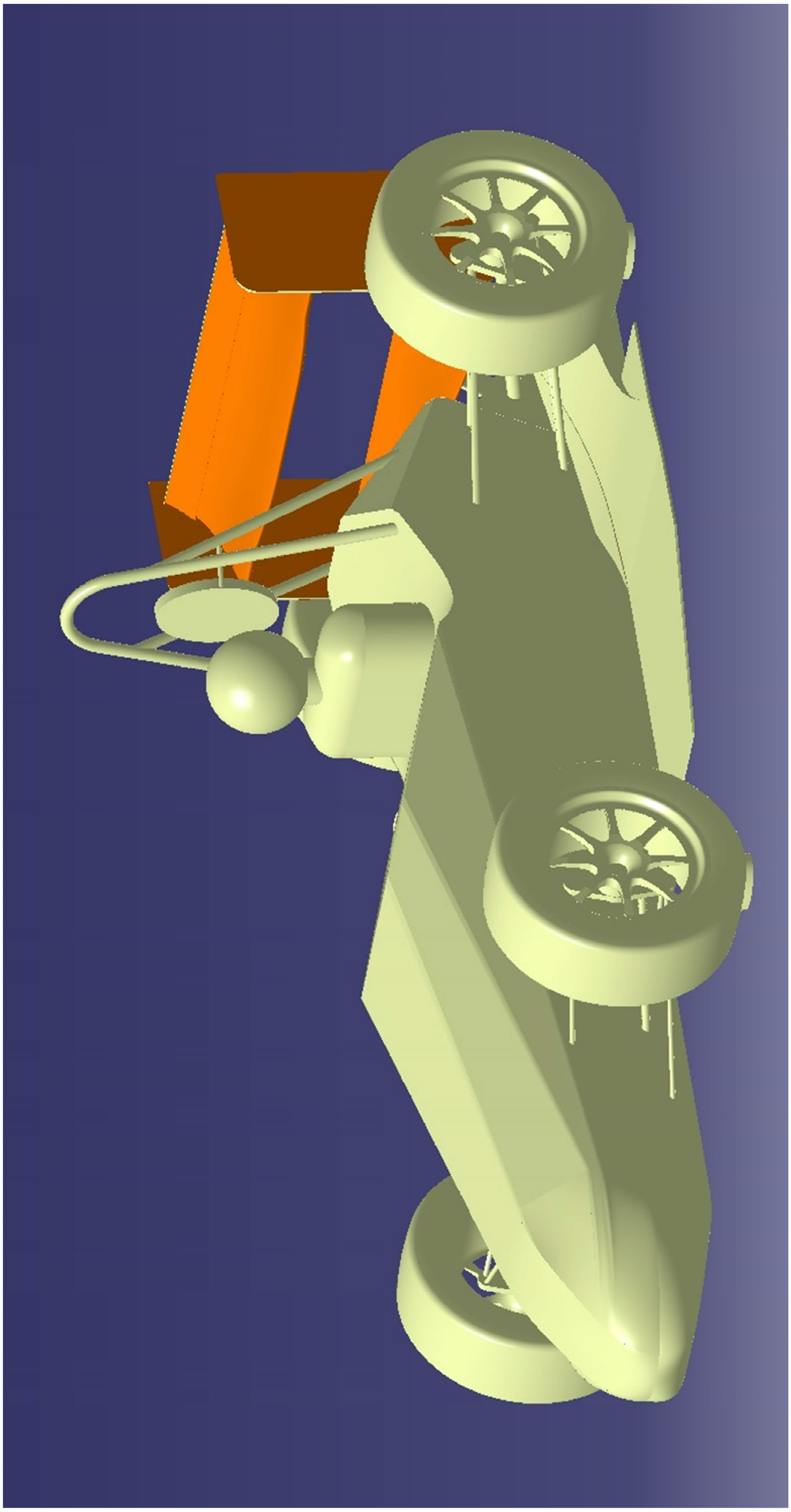

Image 44. Second rear wing design

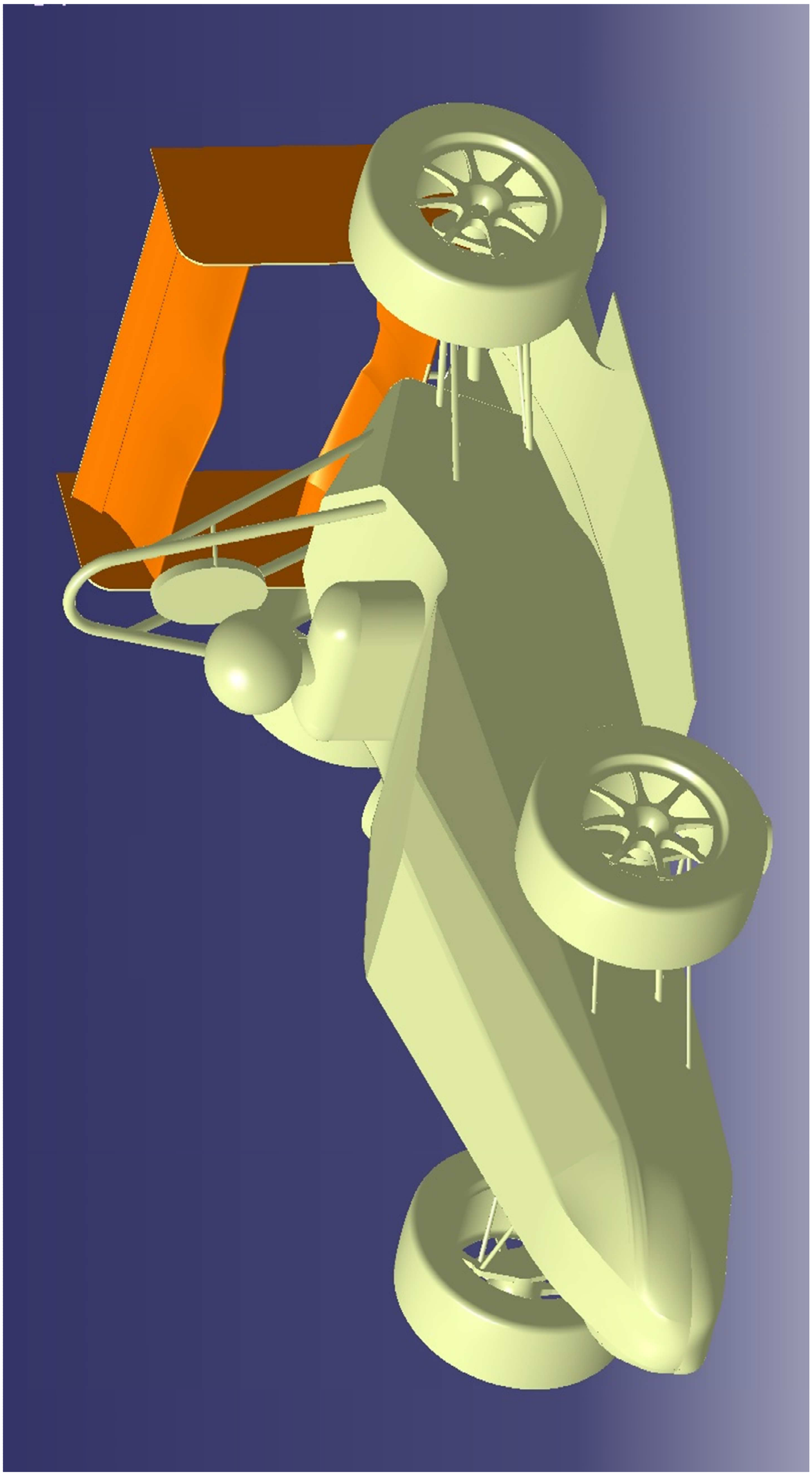

Image 45. Third rear wing design

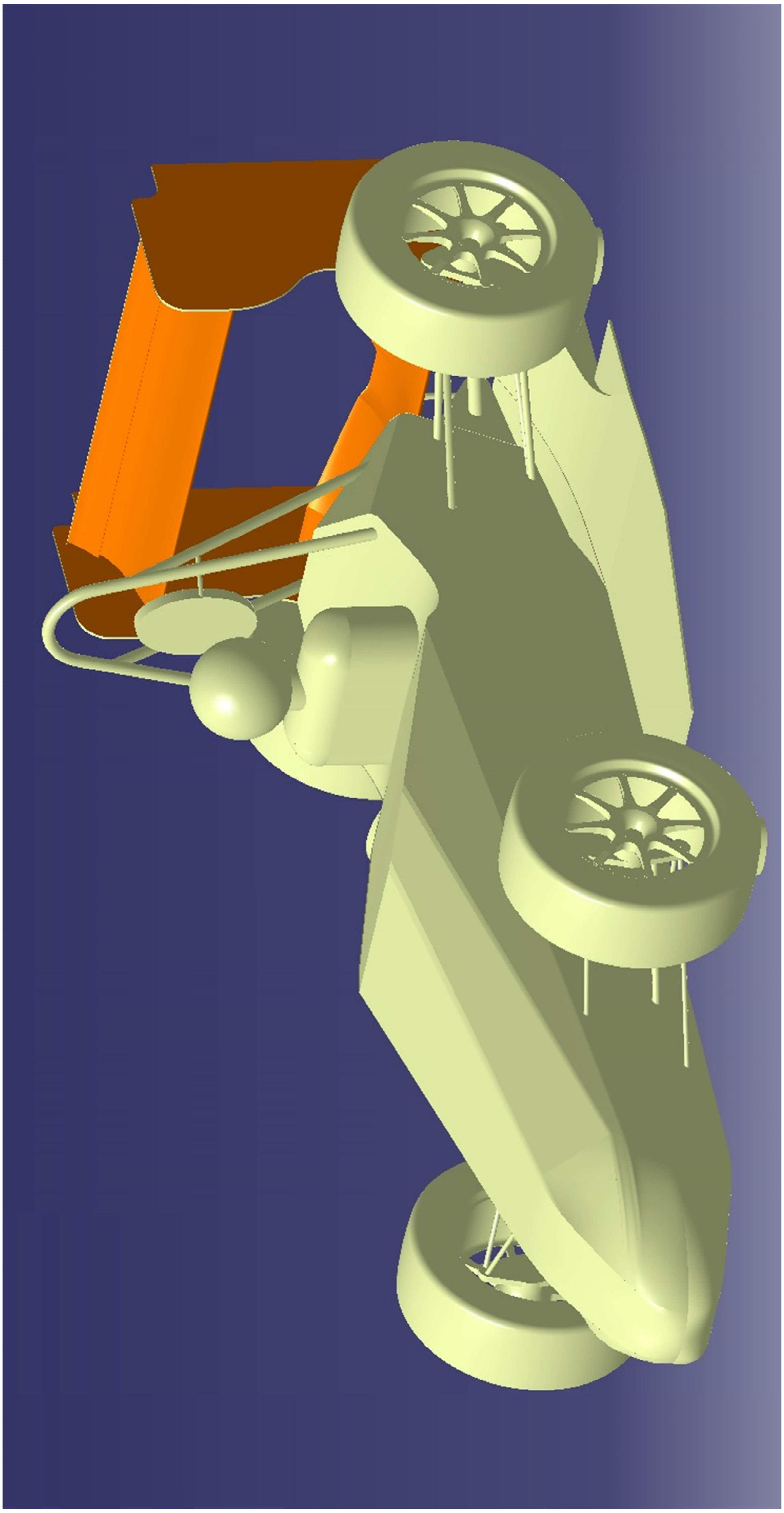

Image 46. Fourth rear wing design

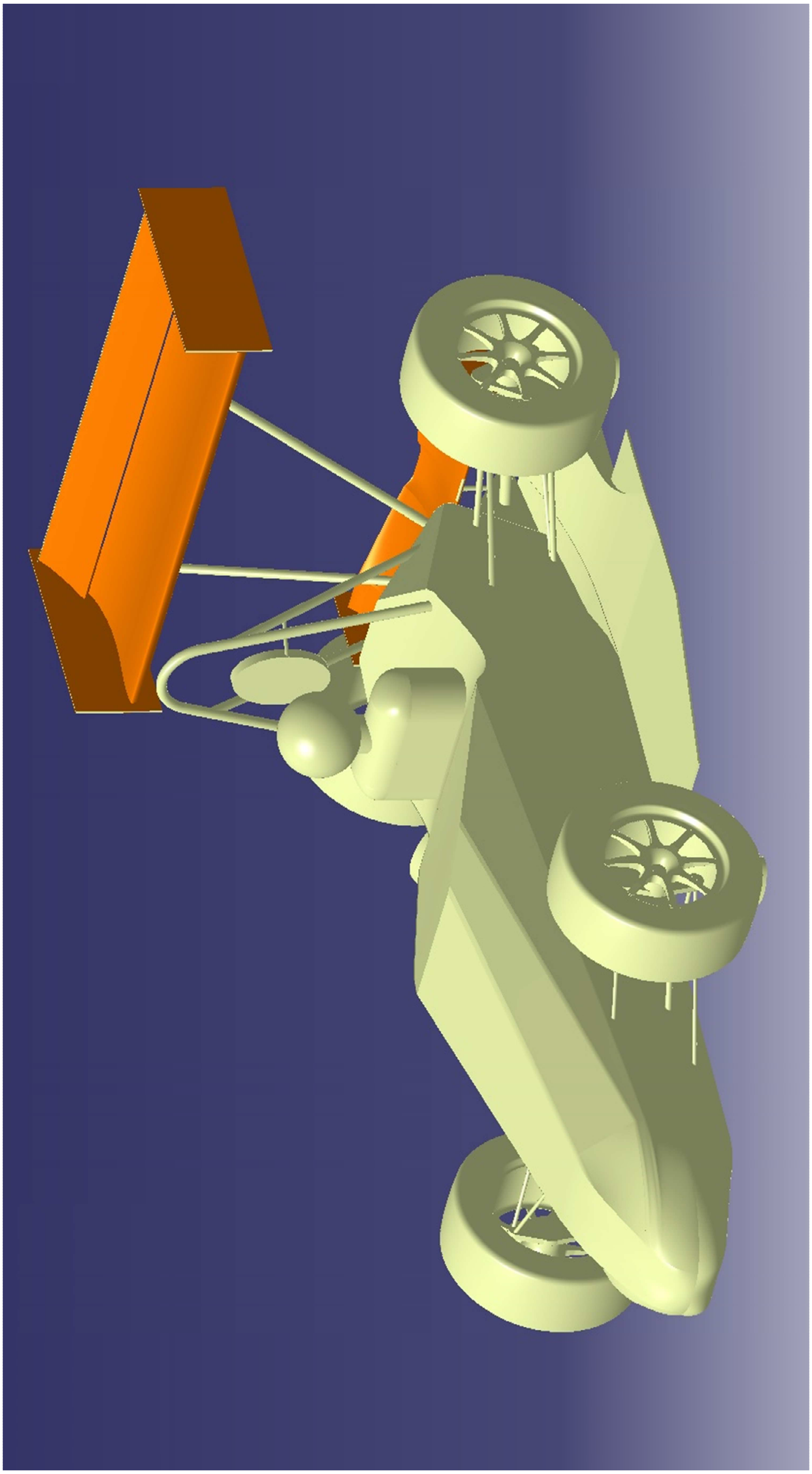

Image 47. Fifth rear wing design

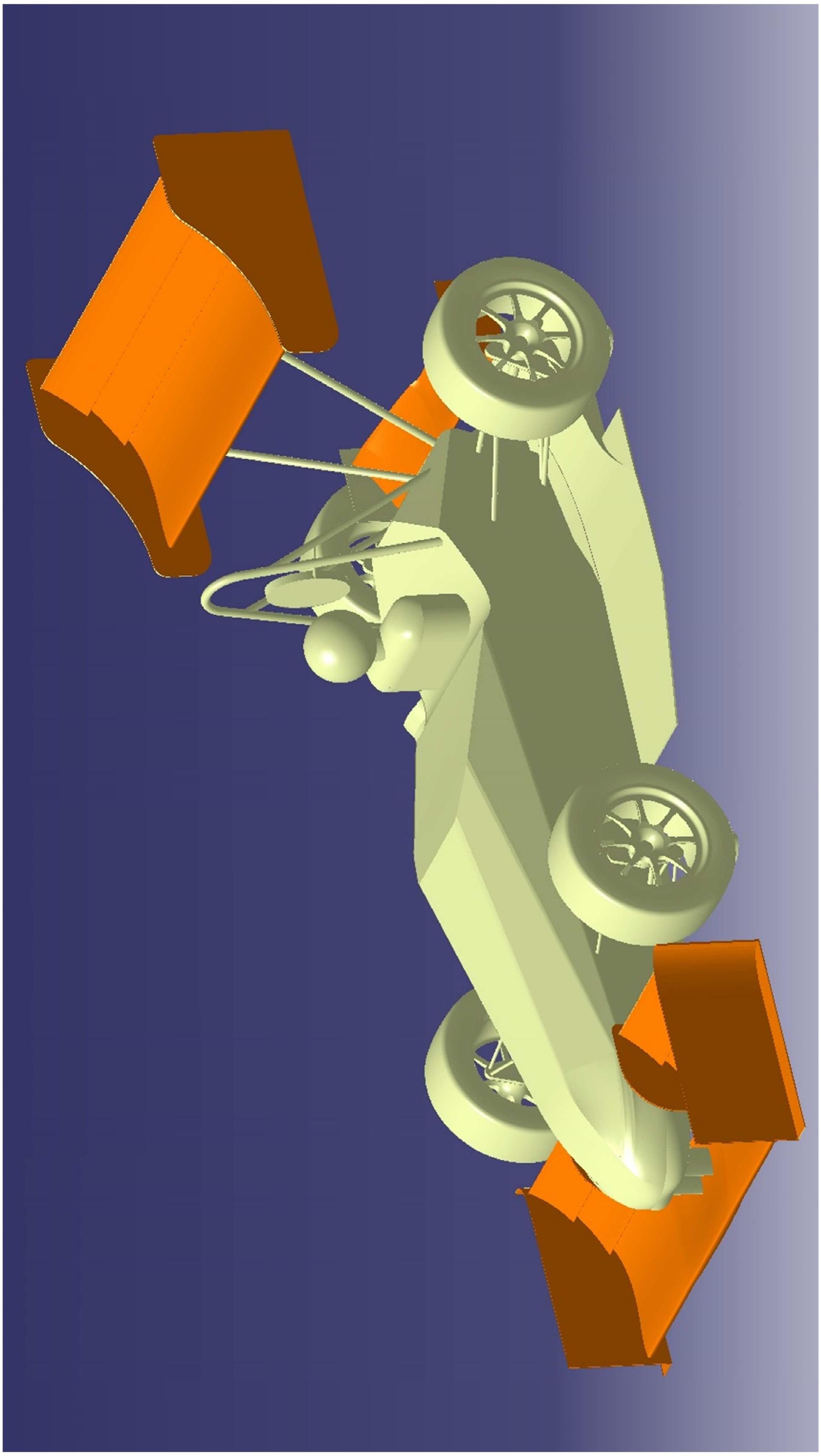

Image 48. Final design with the front wing implemented.