

Laboratory 3-4

Aerodynamic study of the trailer truck

This laboratory work presents the modeling and aerodynamic study of a road train body using dedicated software. During the truck's movement on the road, the forces acting upon the body influence its stability.

The main forces acting on a vehicle's body are: lift force (L), drag force (D), and side force (S). Lift acts perpendicular to the direction of airflow, causing the vehicle to lift up when applied in the positive direction, and when applied in the negative direction, the opposite effect is achieved, resulting in excessive pressure on the wheels.

In equation 1, the expression for this force is presented:

$$F_z = \frac{1}{2} \cdot \rho \cdot V^2 \cdot C_L \cdot A \quad (1)$$

Where:

F_z = Lift force

ρ = Air density = 1.225 kg/m³

V = Airspeed

C_L = Lift coefficient

The forward resistance force is the force acting in the opposite direction to the vehicle's forward motion. The value of this force is very important for determining the final shape of the bodywork.

Equation 2 presents the formula for calculating this force.

$$F_x = \frac{1}{2} \cdot \rho \cdot V^2 \cdot C_D \cdot A \quad (2)$$

Where:

C_D = aerodynamic coefficient

A lower aerodynamic coefficient facilitates better vehicle stability, higher speed for the same fuel consumption, and less noise from the body rubbing against the air. In the case of road trains, the resistance to forward motion is much greater due to the external shape of the cab. To improve the aerodynamic coefficient, designers install deflectors, spoilers, and shields that reduce the turbulence created during operation. The formula for calculating the aerodynamic coefficient is presented in equation 3.

$$C_D = \frac{2 \cdot F_x}{\rho \cdot V^2 \cdot A} \quad (3)$$

The lift coefficient expression is presented in relation 4.

$$C_L = \frac{2 \cdot F_z}{\rho \cdot V^2 \cdot A} \quad (4)$$

The lift coefficient expression is presented in relation 4. Figure 1 presents a sketch that visually shows how aerodynamic forces act on a road train as it travels on the road.

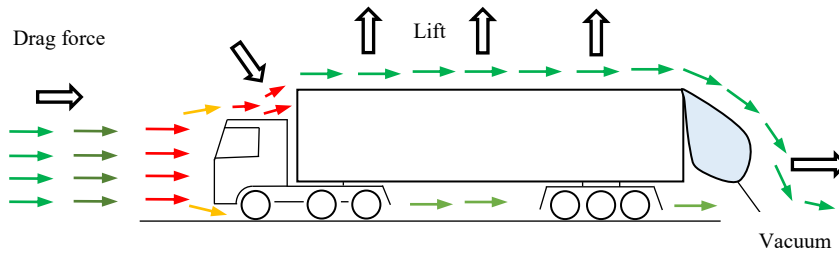


Fig. 1. Aerodynamic forces that occur during road travel.

It can be observed that a volume is formed at the rear of the body, which has a negative effect when driving on the road. The distribution of airflow streamlines in a virtual environment can be determined by following the steps presented in Figure 2, which shows the logical diagram of the iterative fluid dynamics calculation process.

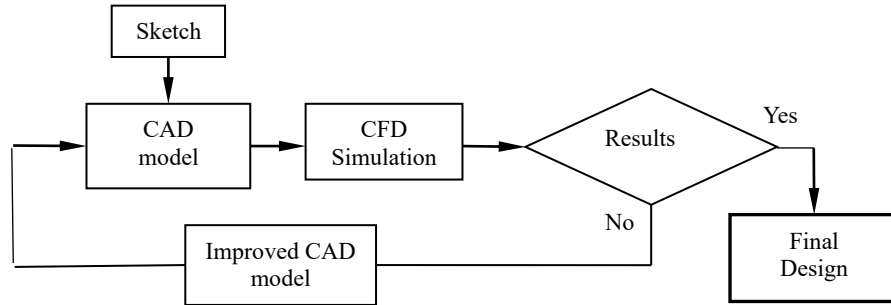


Fig. 2. Conceptual structure of the process

The first step in conducting a flow study for a vehicle body is sketching the model. The proposed CAD model of the car body is introduced into the CFD simulation module, where the calculation domain, gas type (in this case, air), air velocity, etc., are defined. The results obtained from the simulation are analyzed, and if they meet the required specifications, the final body design is obtained. If the results do not meet the required criteria, the car body CAD model will be improved and will go through the CFD process steps until the results meet the required criteria.

I. CAD modeling

Modeling the track cabin

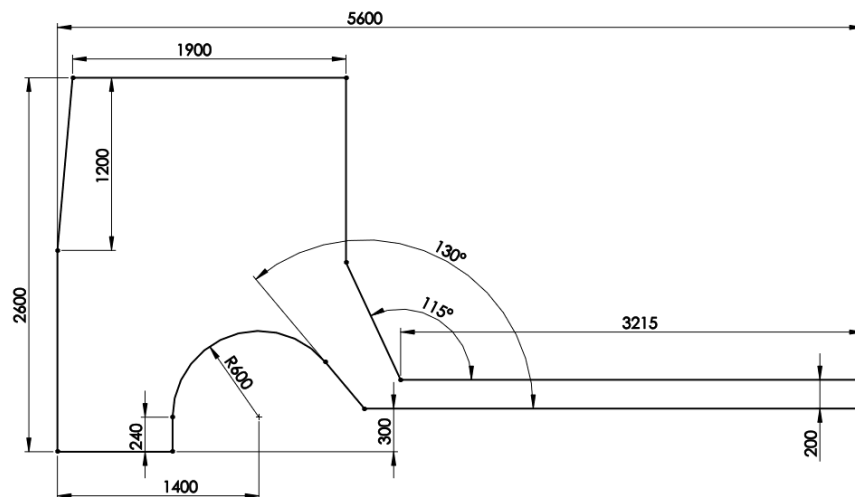
The steps required for modeling this component are presented as follows:

1. Modeling the Body Outline

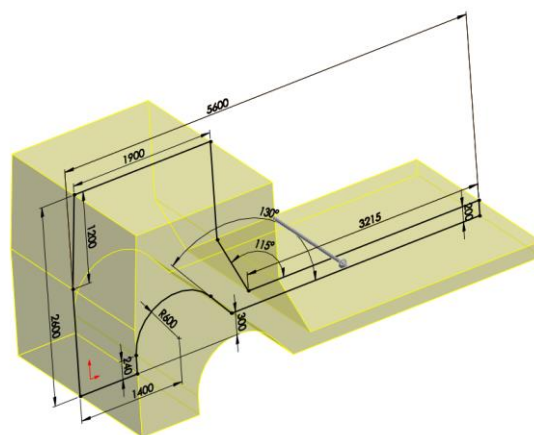
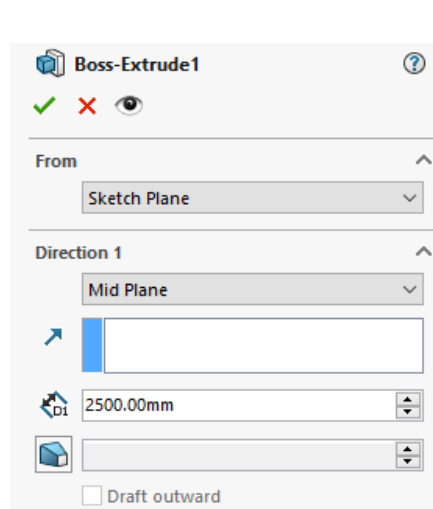
The outline is sketched from the **Feature Manager** toolbar by selecting the **Right Plane** on which the first sketch will be drawn, defining the cab shape. Select the

Sketch  toolbar, where the **Line** , **Circle** , **Trim Entities** , and

Smart Dimension  commands will be used to create the following sketch according to the dimensions.

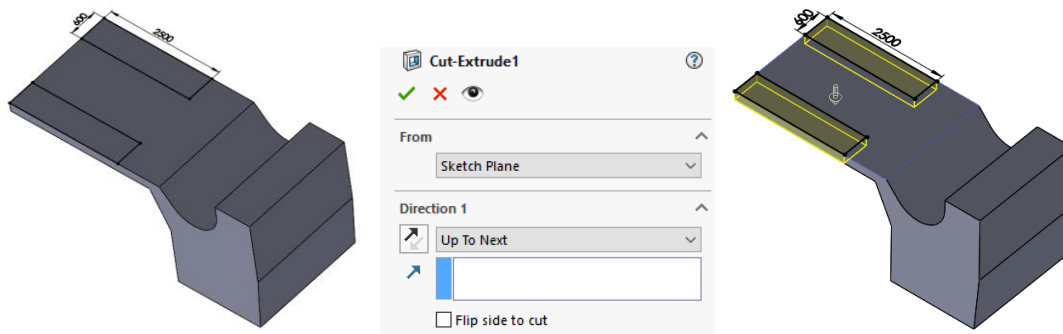


From the **Features**, select the **Boss-Extrude** command. The sketch is extruded to 2500 mm, on both sides of the sketch, by selecting the **Mid Plane** command.



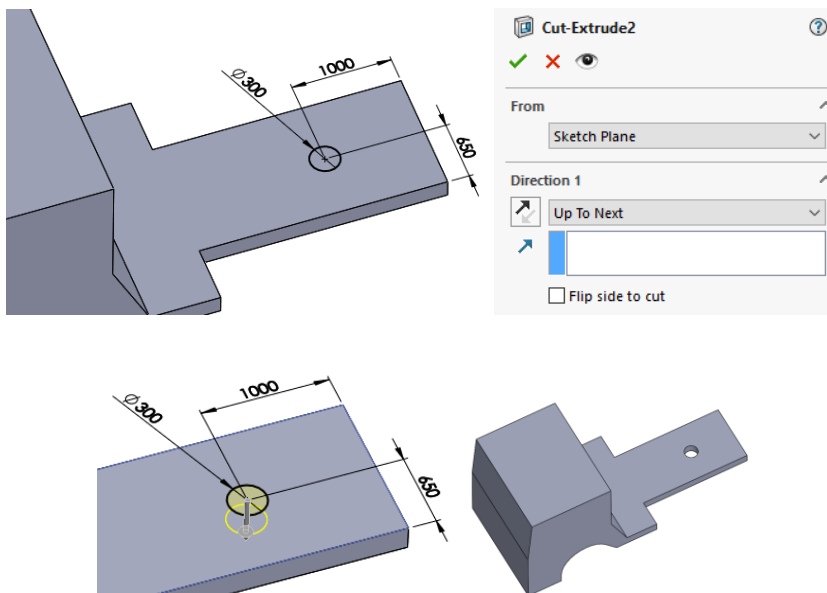
1. Creating the housing for the drive wheels

Using the Sketch tools, draw two rectangles with a length of 2500 mm and a width of 600 mm on the lower surface of the model using the **Rectangle**  command. From the **Features** toolbar, select the **Cut-Extrude** command. The resulting sketch will remove the model from within the sketch.



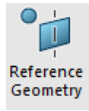
2. Creating the joint coupling

From the **Sketch** tools, on the surface of the tractor unit chassis, using the **Circle**  command, a circle with a diameter of 300 mm is drawn, positioned 650 mm from the front edge and 1000 mm from the rear of the tractor unit. From the **Features** toolbar, select the **Cut-Extrude** command. The resulting sketch will remove the model inside the circle.

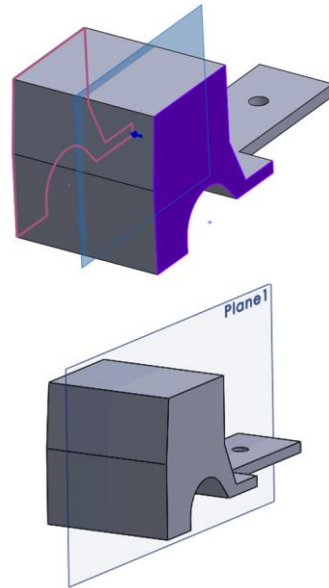
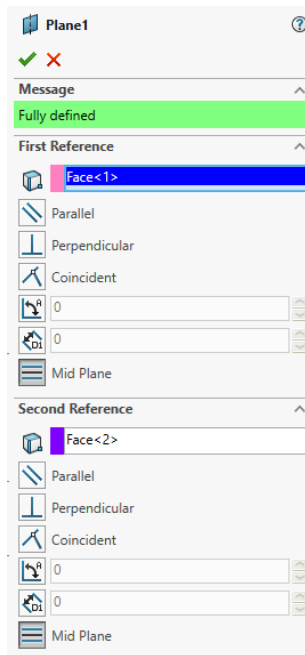


3. Creating a longitudinal plan positioned in the middle of the cabin

From the **Features** toolbar opens the **Reference Geometry**

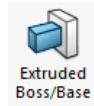


submenu, where you select the **Plane**  **Plane** command. To insert a mid-body plane, select the outer surfaces of the cab with the mouse. The plane's position is automatically calculated at the midpoint between the two selected surfaces. By left-clicking **OK**  with the mouse, the plan is created.

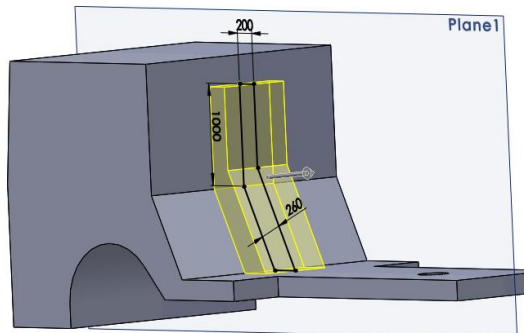
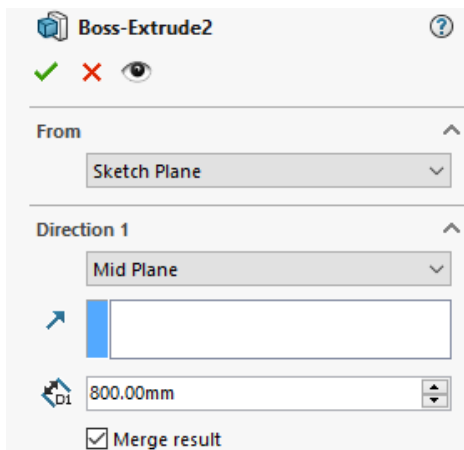
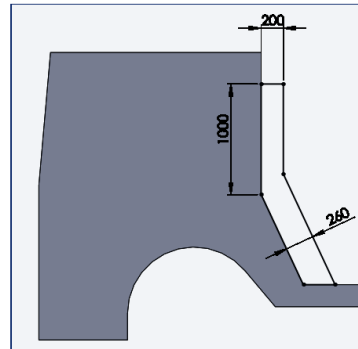


4. Modeling the auxiliary connection equipment located behind the cabin

On the plane created using the **Line**  command, the sketch is drawn that defines the shape of the recess for the connecting installations. The dimensions of the sketch are shown in the adjacent image. From the



Tools tab, select the **Boss-Extrude** command. The sketch is extruded to 800 mm, on both sides of the sketch, by selecting the **Mid Plane** command.

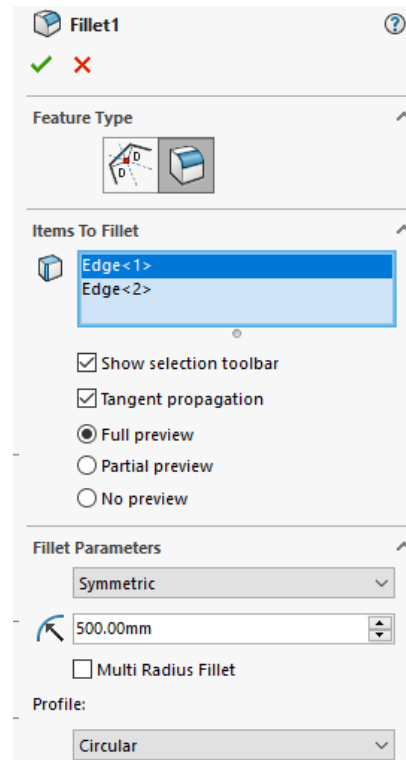
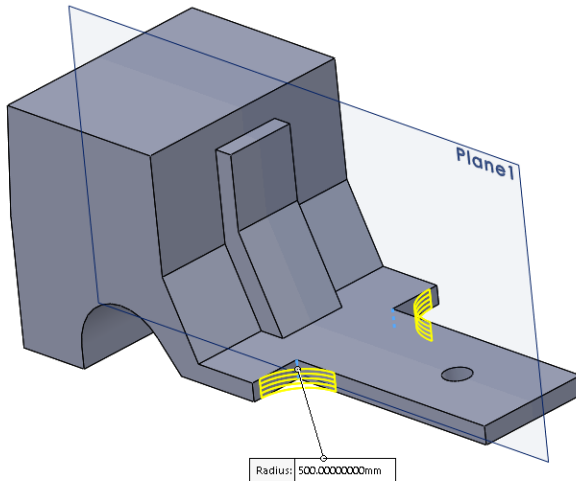


5. Edge Rounding

From the **Features** toolbar, select the **Fillet**

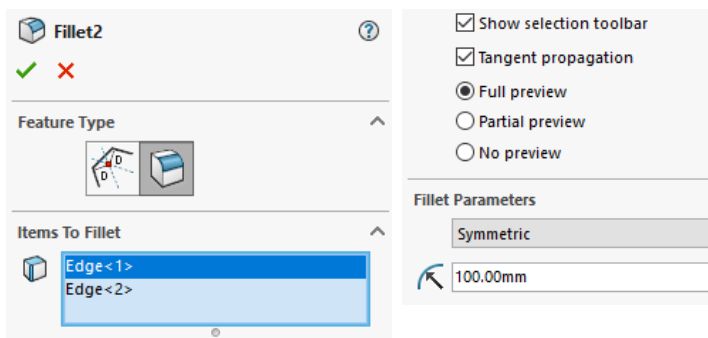
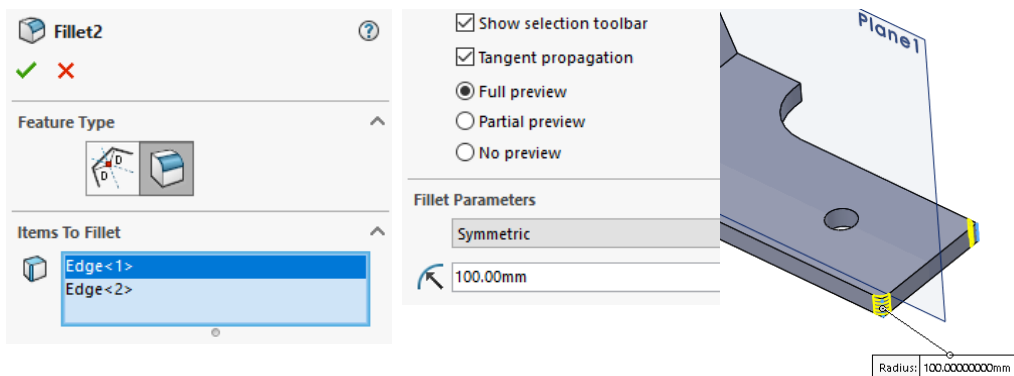


command. The indicated edges are rounded to a radius of 500 mm.



6. Rear Edge Rounding

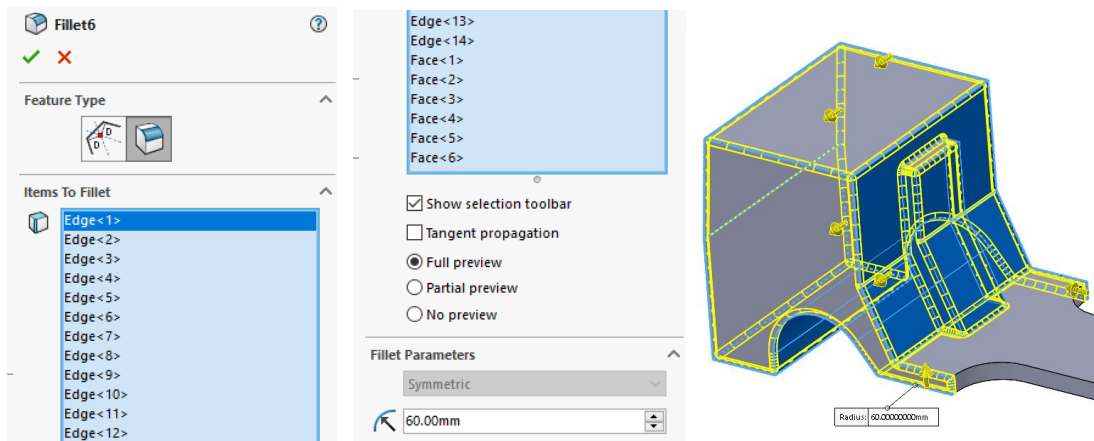
From the **Features** toolbar, select the **Fillet** command. The indicated edges are rounded to a radius of 100 mm.



7. Cabin Edge Rounding

From the **Features** toolbar, select the **Fillet** command. The indicated edges are rounded to a radius of 60 mm.

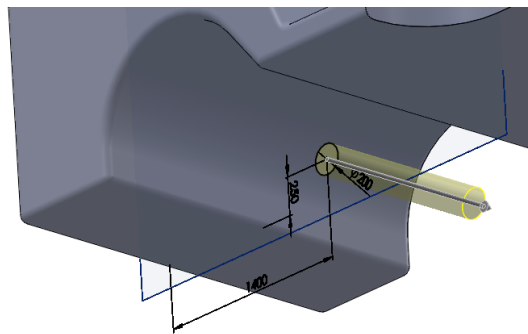
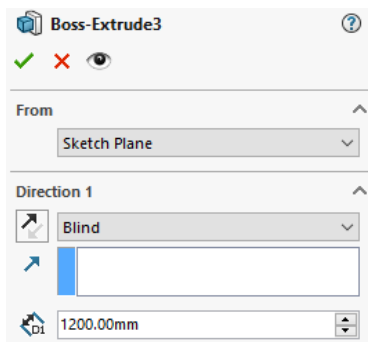
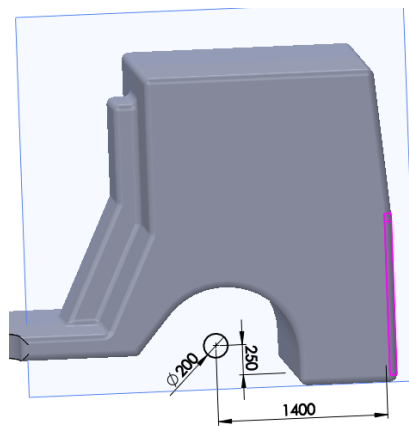




8. Steering Axis Modeling

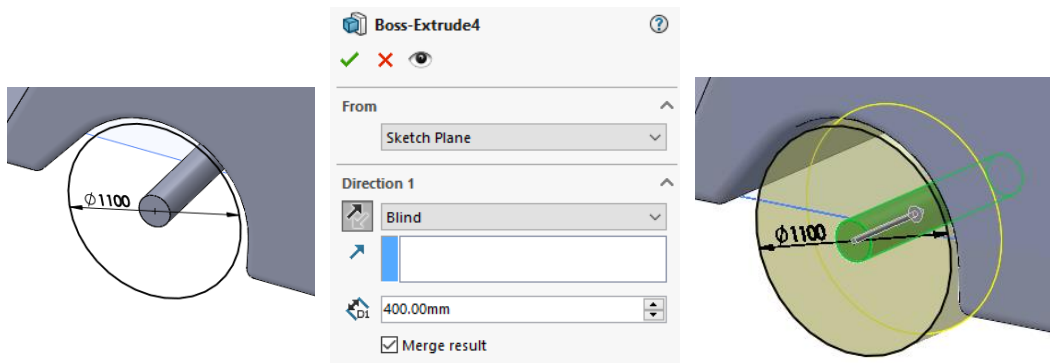
From the **Sketch** tools, on the surface of the tractor head's midplane, using the **Circle**

 command, a circle with a diameter of 200 mm is drawn, positioned 250 mm from the bottom of the cab and 1400 mm from the front of the tractor head. From the **Tools** tab, select the **Boss-Extrude** command. The sketch is extruded to 1200 mm.



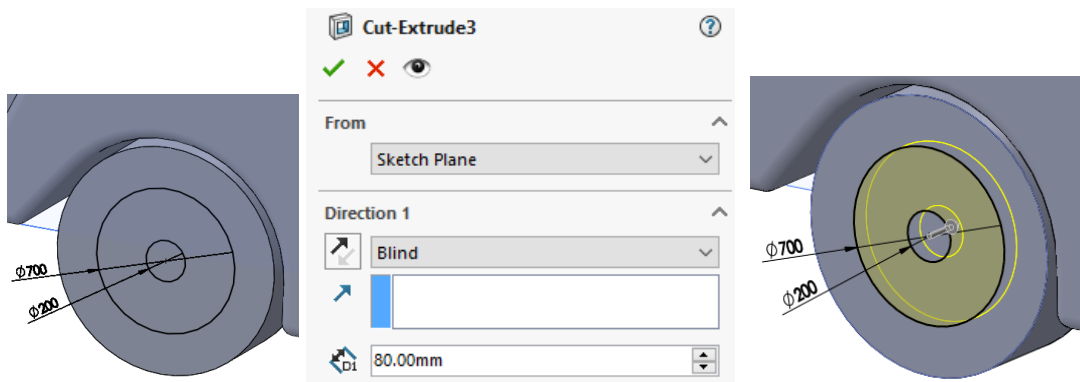
9. Modelarea unei roți

On the front surface of the axis, a circle with a diameter of 1100 mm is drawn from the **Sketch** toolbar. From the **Features** toolbar, select the **Boss-Extrude** command, and extrude the circle 400 mm toward the inside of the cabin.



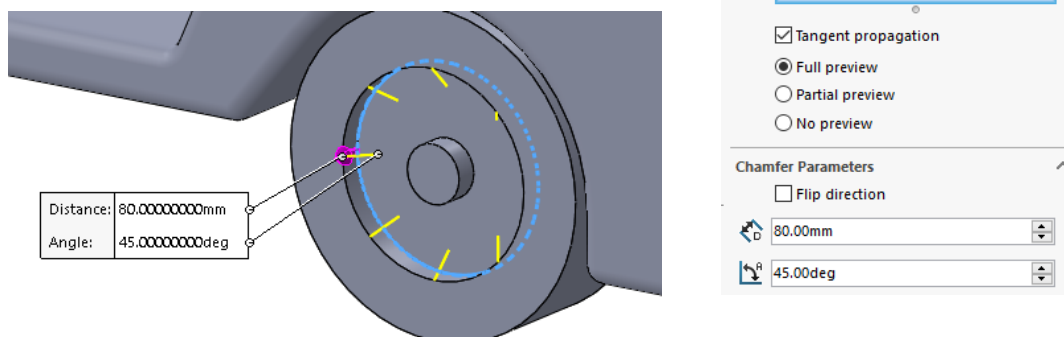
10. Cutting out the shape from the wheel

The cutout in the wheel is made by drawing a new sketch consisting of two circles with diameters of 700 and 200 mm. Using the **Cut-Extrude** tool, the model between the two circles is removed over 80 mm.



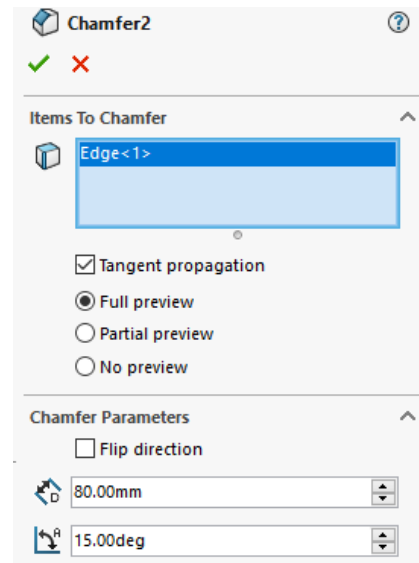
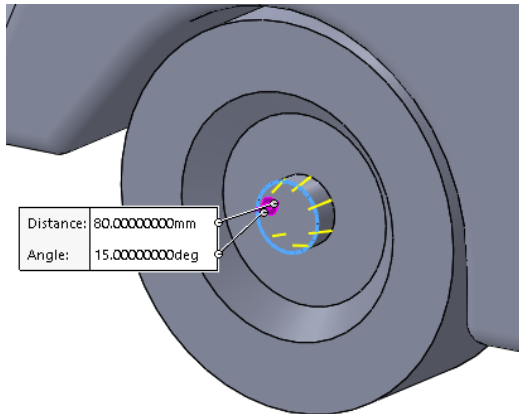
11. Chamfering the edge on the wheel

From the Tools toolbar, select the **Chamfer** command. The indicated edge is selected and chamfered at 80 mm with a 45° angle.



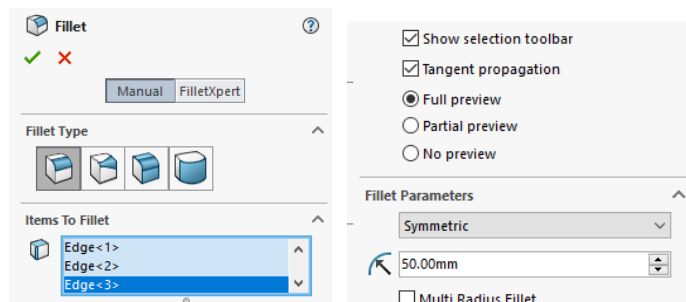
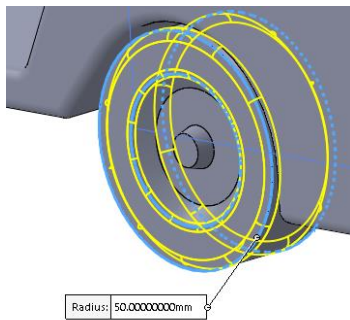
12. Chamfering the edge of the wheel hub

From the **Features** toolbar, select the **Chamfer**  command. The indicated edge is selected and chamfered at 80 mm with a 45° angle.



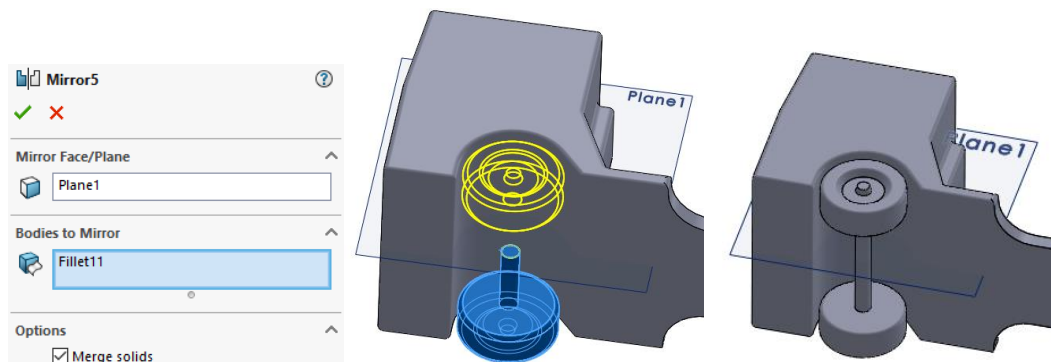
13. Rounding the outer edges of the tyre

From the **Features** toolbar, select the **Fillet** command. The indicated edges are rounded to a radius of 50 mm.



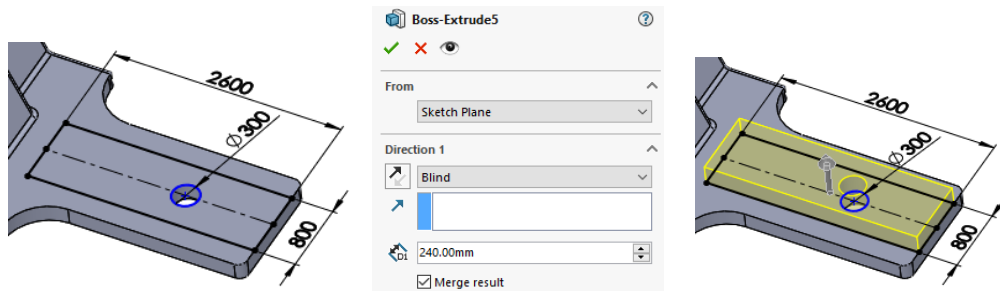
14. Axis and Wheel Mirroring

From the **Features** tab, select the **Mirror**  command. From **Body to Mirror**, the wheel and axle that are mirrored with respect to the tractor's midplane chosen at **Mirror Face/Plane** are selected.



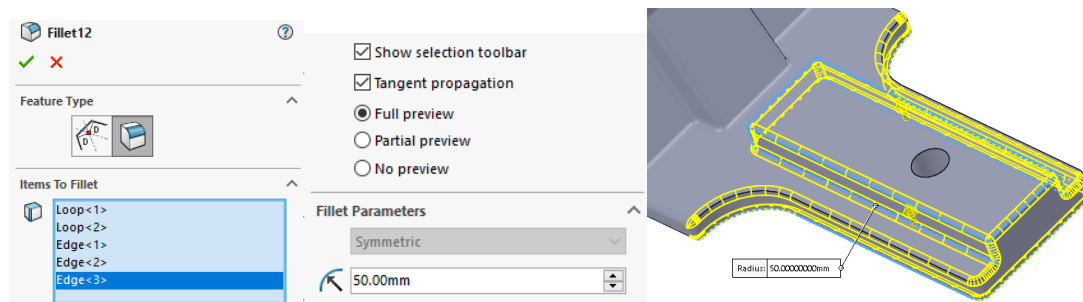
15. Modeling the location for auxiliary and connection installations

From the **Sketch** tools, draw a rectangle with a length of 2600 mm and a width of 800 mm, and a circle with a diameter of 300 mm. From the **Features** tab, select the **Boss-Extrude** command. The sketch is extruded to 240 mm.



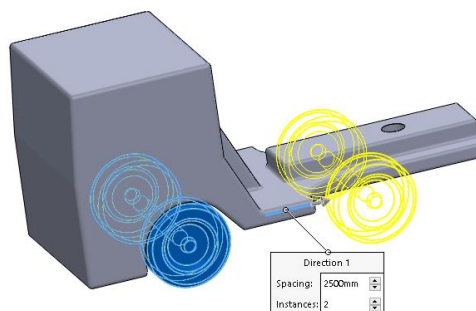
16. Rounding the outer edges of the cabin

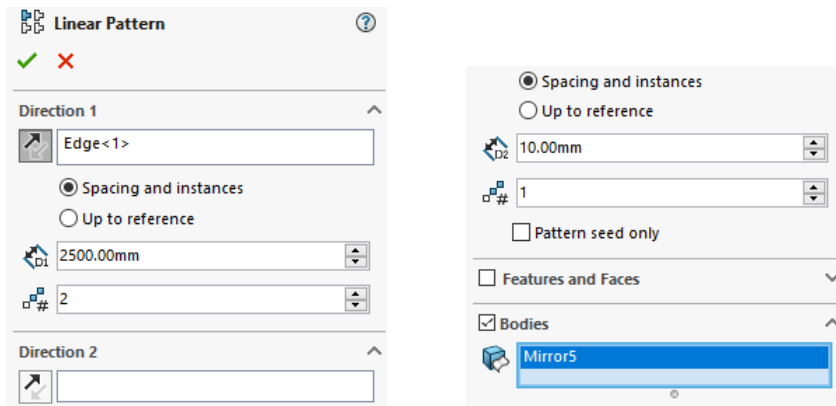
From the **Features** toolbar, select the **Fillet** command. The indicated edges are rounded to a radius of 50 mm.



17. Modeling Drive Shafts Using Linear Axis Multiplication

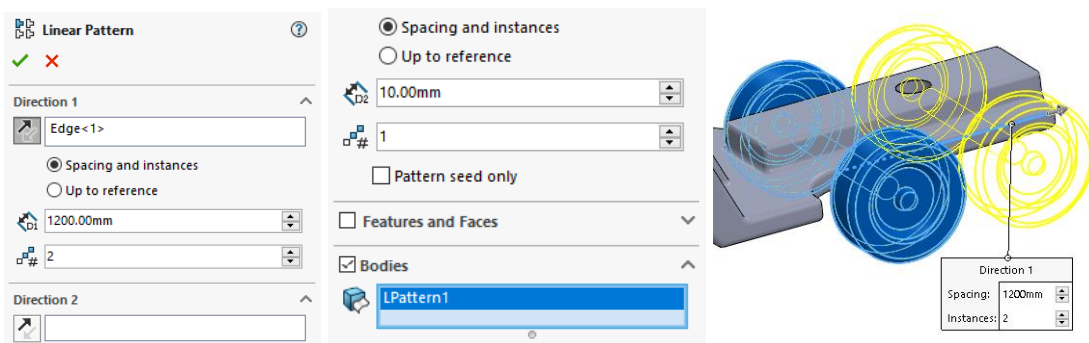
From the **Features** toolbar, select the **Linear Pattern** command. The steering axle multiplies linearly over 2500 mm, choosing a longitudinal edge of the truck cabin as the direction.





18. Multiplication of the second drive axle

From the **Features** toolbar, select the **Linear Pattern** command. The second drive axle is multiplied using the axle model obtained in the previous step. This axle is linearly multiplied at 1200 mm, choosing a longitudinal edge of the tractor head as the direction.

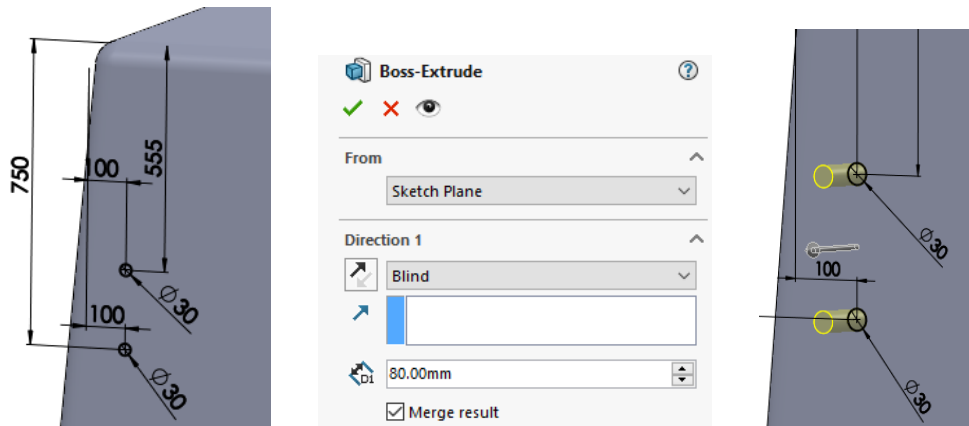


19. Modeling the mirror support on the left side of the tractor head

From the **Sketch** tools, on the surface of the tractor head, using the

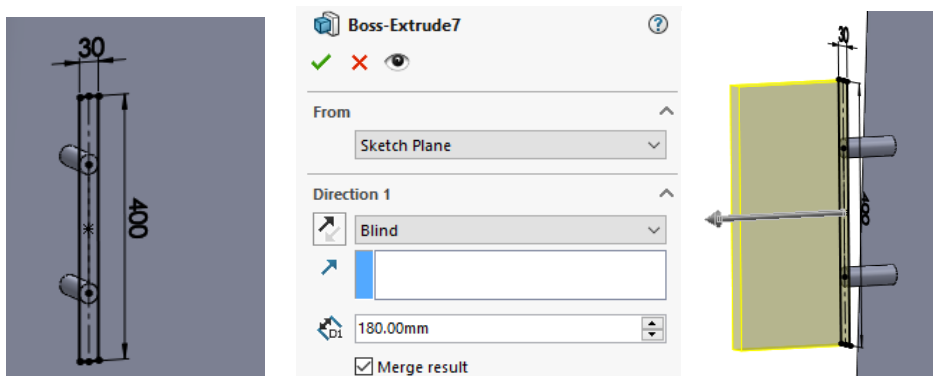
Circle  command, draw two circles with a diameter of 30 mm, positioned according to the sketch below.

To model the sketch, the **Boss-Extrude** command is selected from the **Features** toolbar. The sketch is extruded to 80 mm.



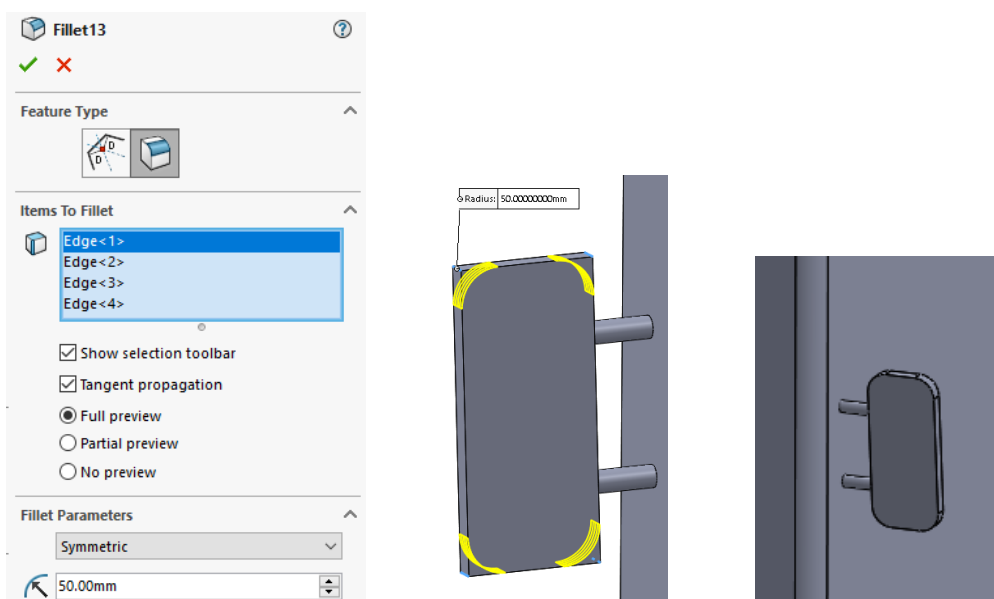
20. Mirror modeling

On the front surface of the modeled support, a rectangle with a length of 400 mm and a width of 30 mm is drawn from the **Sketch** toolbar. From the **Features** toolbar, the sketch is modeled with the **Boss-Extrude** command to 180 mm.



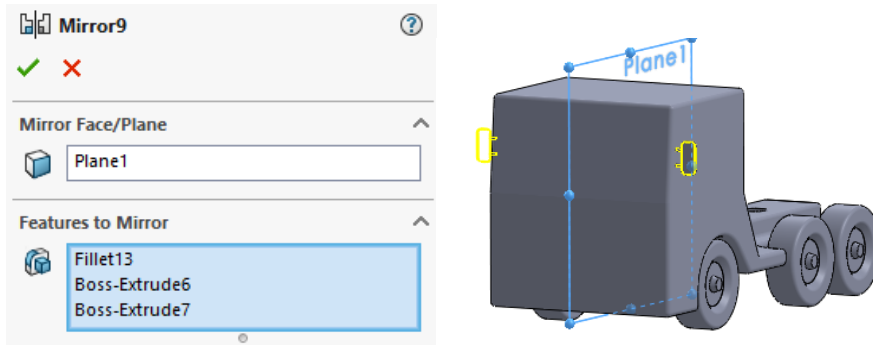
21. Mirror Rounding

From the **Features** toolbar, select the **Fillet** command. The indicated edges are rounded to a radius of 50 mm.

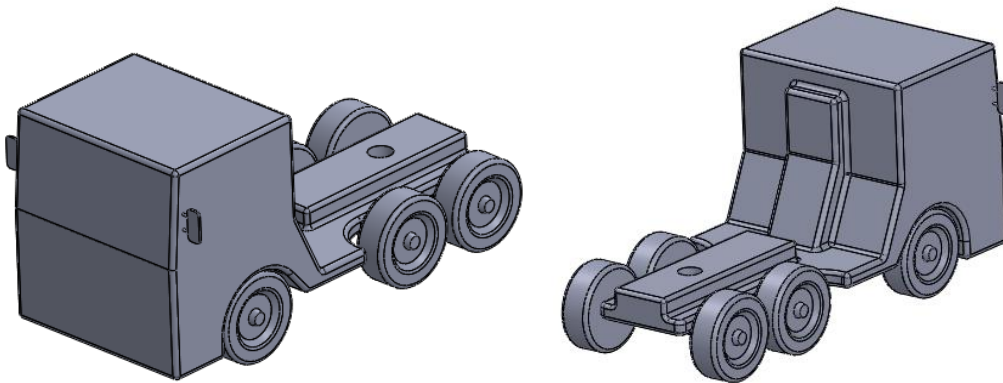


22. Creating a mirror on the right side of the tractor unit

From the **Features** tab, select the **Mirror** command. From **Features to Mirror**, you select the extruded support, the mirror, and the mirror rounding that are mirrored across the midplane of the track cabin chosen in **Mirror Face/Plane**.



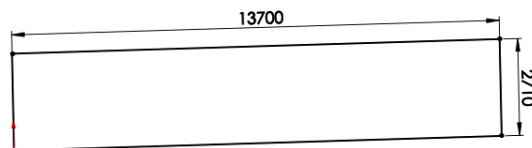
The final model of the track cabin

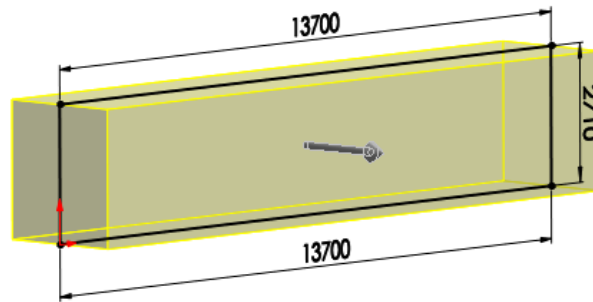
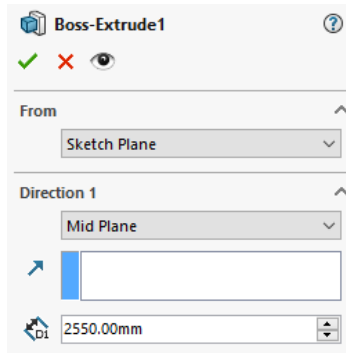


Trailer Modeling

1. Modeling the wagon

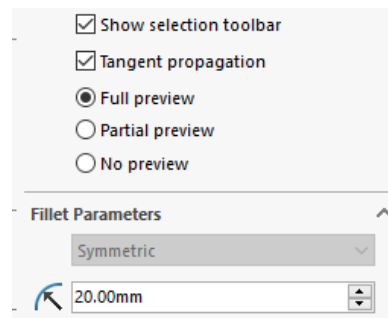
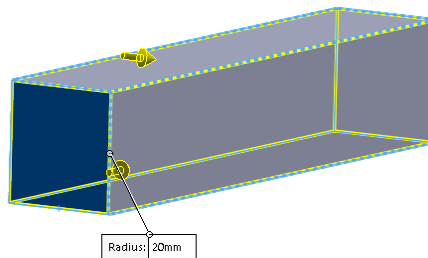
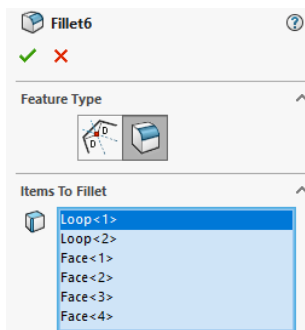
From the **Sketch** tools, a rectangle is drawn with a length of 13700 mm and a width of 2710 mm. From the **Features** tab, select the **Boss-Extrude** command. The sketch is extruded on both sides to 2550 mm.





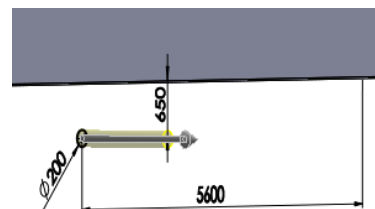
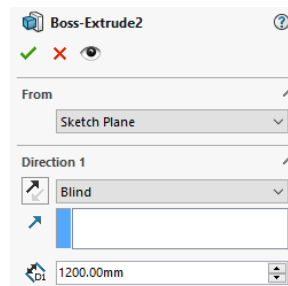
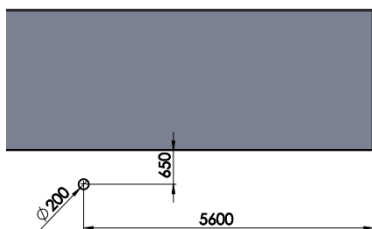
2. Rounding the edges of the wagon

From the **Features** toolbar, select the **Fillet** command. The indicated edges are rounded to a radius of 20 mm.



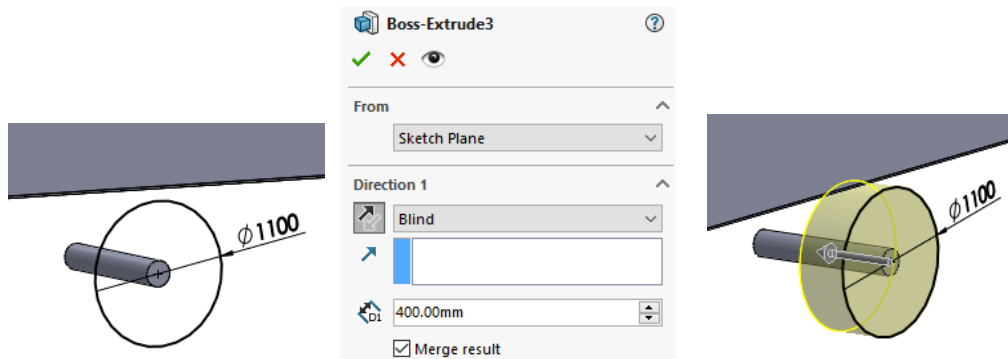
3. Axis Modeling

On the surface of the side plane, which is positioned longitudinally through the middle of the wagon from the **Sketch** toolbar, a circle with a diameter of 200 mm is drawn. From the **Features** toolbar, the sketch is extruded using the **Boss-Extrude** command to 1200 mm.



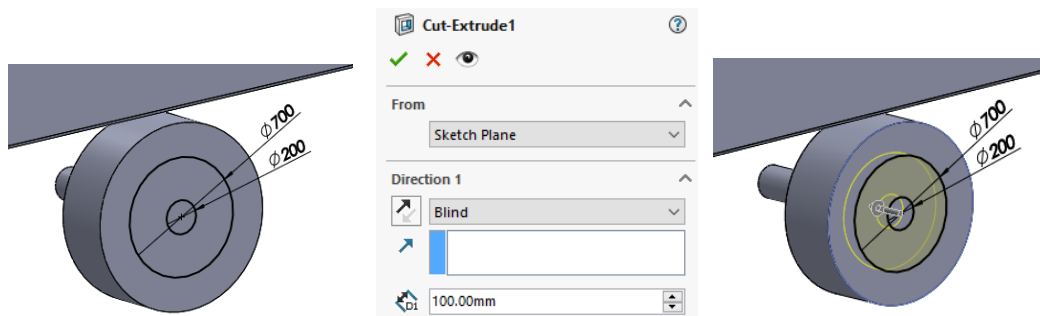
4. Wheel Modeling

On the front surface of the wagon axle, draw a circle with a diameter of 1100 mm from the **Sketch** toolbar. From the **Features** toolbar, the sketch is extruded inward into the wagon using the **Boss-Extrude** command for a distance of 400 mm.



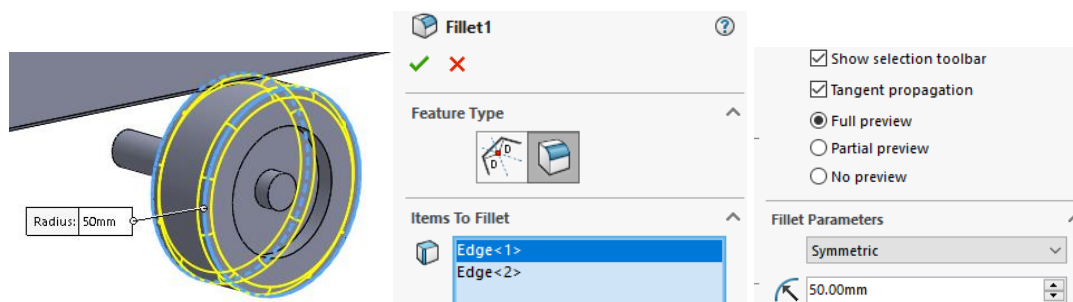
5. Cutting out the shape from the wheel

From the **Sketch** tools, a new sketch is drawn consisting of two circles with diameters of 700 and 200 mm. The model between the two circles is removed over 100 mm using the **Cut-Extrude** tool.



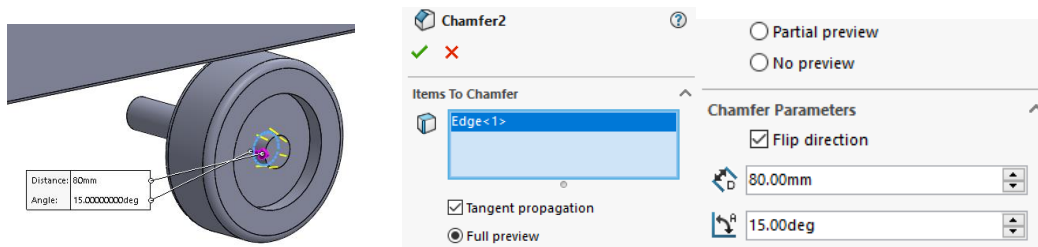
6. Rounding the outer edges of the wheel

From the **Features** toolbar, select the **Fillet** command. The indicated edges are rounded to a radius of 50 mm.



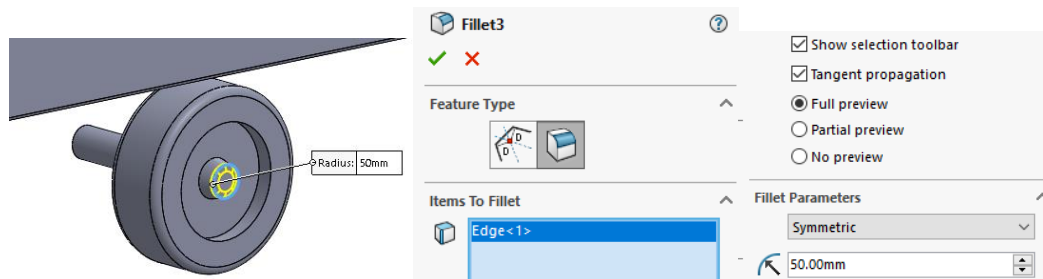
7. Chamfering the edge of the wheel hub

From the **Features** toolbar, select the **Chamfer**  command. The indicated edge is selected and chamfered at 80 mm with a 15° angle.



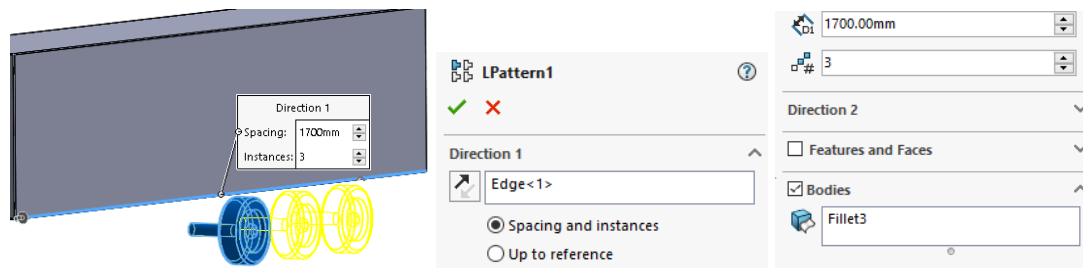
8. Rounding the outer edge of the hub

From the **Features** toolbar, select the **Fillet** command. The indicated edge is selected and rounded to 50 mm.



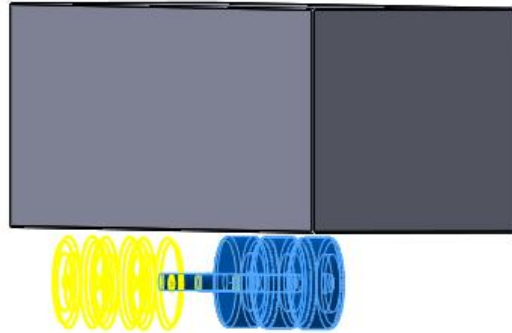
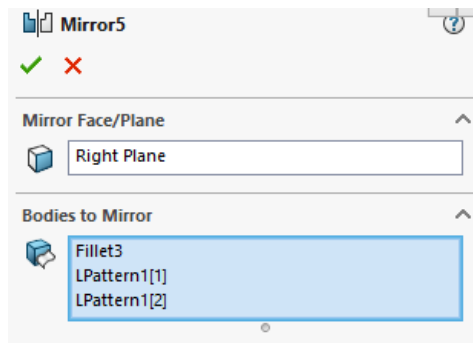
9. Axle and Wheel Multiplication

From the **Features** toolbar, select the **Linear Pattern** command. The wheel axle is linearly multiplied at 2500 mm, choosing a longitudinal edge of the wagon as the direction.



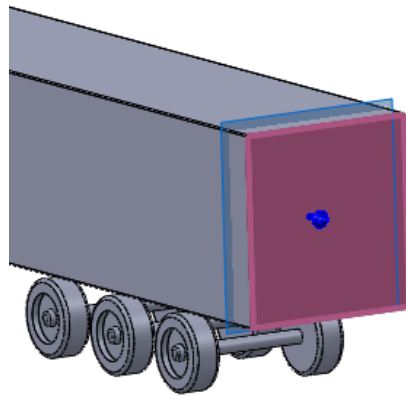
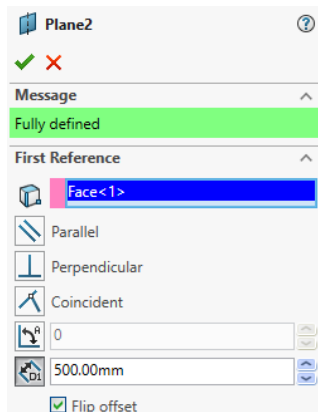
10. Mirroring the axles and wheels on the right side of the wagon

From the **Features** tab, select the Mirror command. From **Body to Mirror**, the wheels and axles are selected to be mirrored with respect to the midplane of the car chosen in **Mirror Face/Plane**.



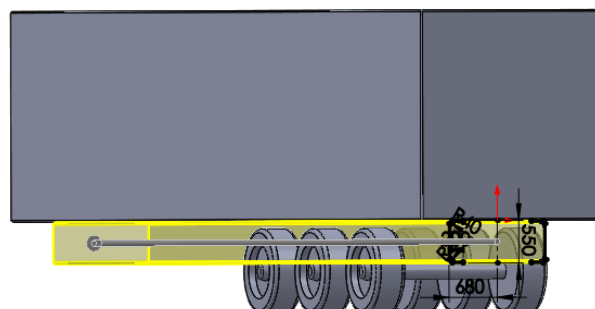
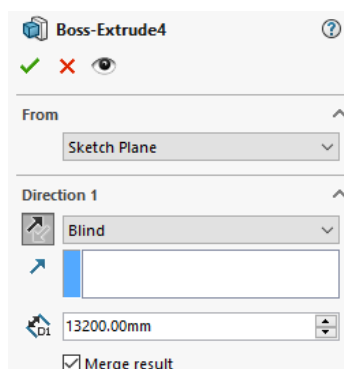
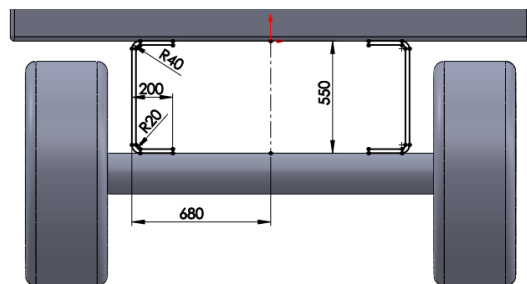
11. Construction plan for the stringers

The outline of the stringers will be drawn on the plan introduced from the Features toolbar. The **Reference Geometry** submenu is open, where the **Plane** command is selected. The plan is located 500 mm away from the flat surface of the rear part of the wagon.



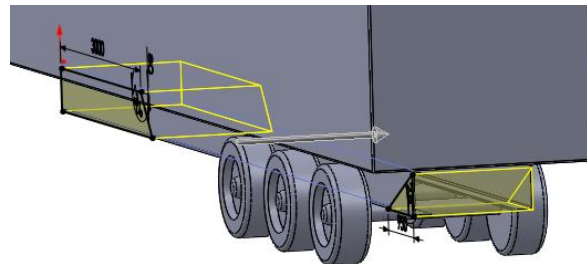
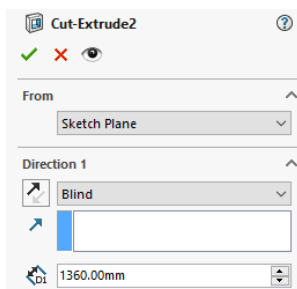
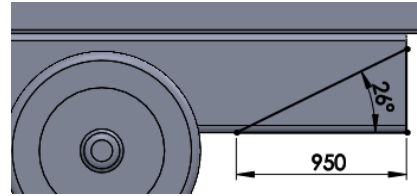
12. Rails modeling

On the created plane, the sketch shown in the adjacent image is introduced from the **Sketch** toolbar. From **Features**, the sketch is extruded to 13200 mm.



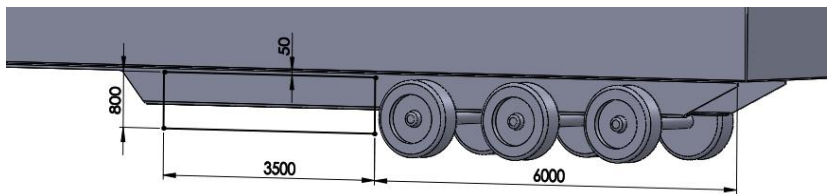
13. Creating cutouts from stringers

Using only the **Sketch** tools, two sketches are drawn according to the images below, located on the face of a stringer. The inner surface of these sketches is removed over 1360 mm using the **Cut-Extrude** command in the **Features** toolbar.

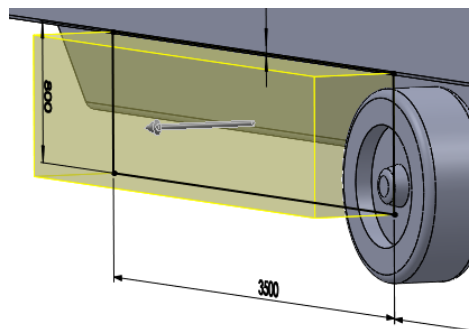
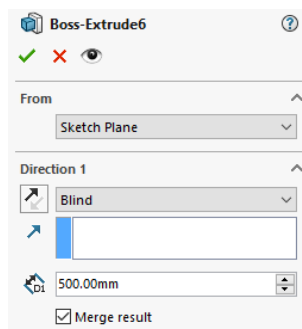


14. Modeling a Storage Space

On the outer surface of the left-side longitudinal member, draw a rectangle from the **Sketch** toolbar, positioned as shown in the figure below.

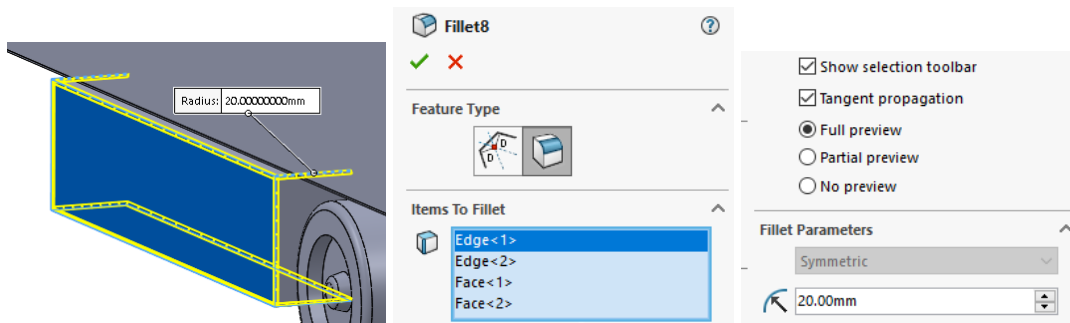


The sketch is extruded 500 mm using the **Boss-Extrude** command.



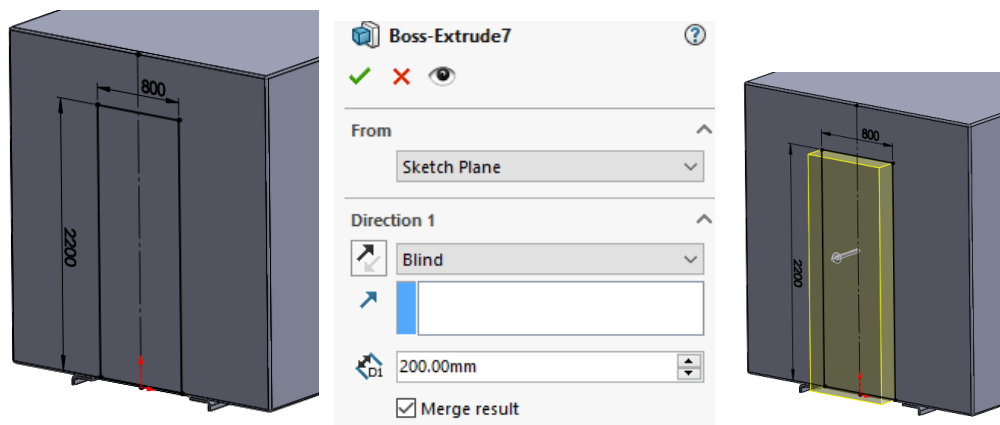
15. Rounding the edges of the storage space

From the **Features** toolbar, select the **Fillet** command. The indicated edges are selected and rounded to a radius of 20 mm.



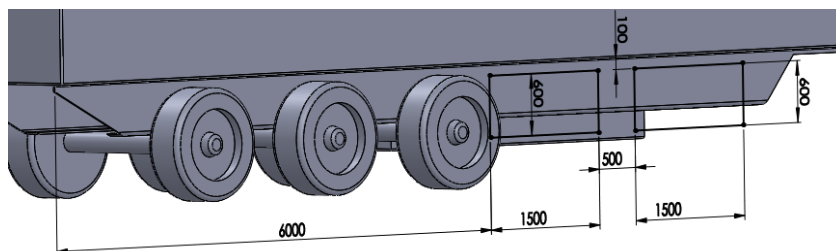
16. Modeling the space containing the auxiliary and connecting elements

On the front surface of the wagon, from the **Sketch** toolbar, a rectangle 2000 mm long and 800 mm wide is drawn, positioned in the middle of the wagon, as shown in the image below. The sketch is extruded from the **Features** toolbar using the **Boss-Extrude** command to 200 mm.

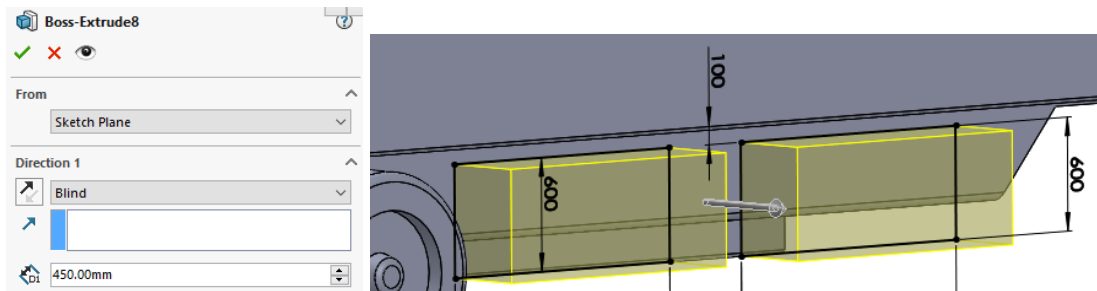


17. Modeling the wagon's auxiliary equipment

On the outer surface of the right-side longitudinal member, draw two rectangles from the **Sketch** toolbar, positioned as shown in the figure below.

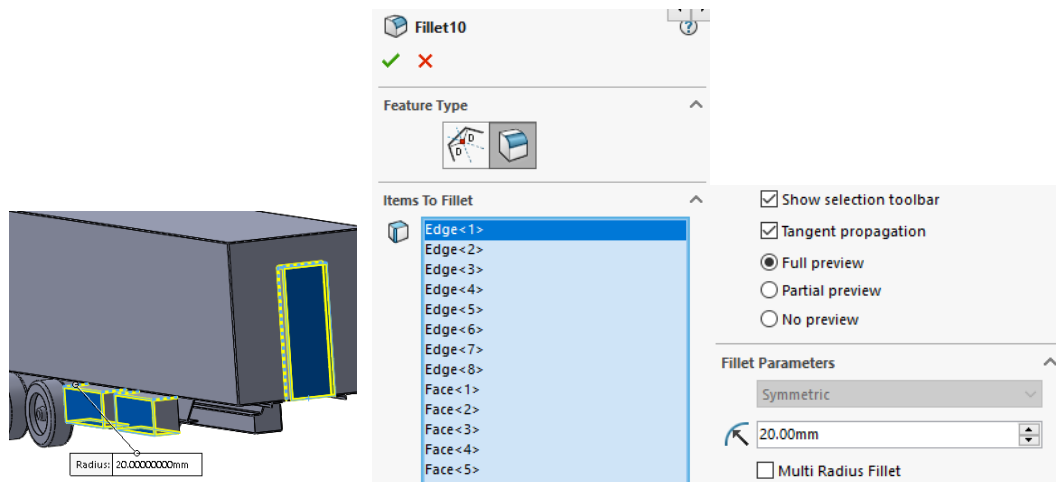


The sketch of the tool **Features** is extruded to 450 mm using the **Boss-Extrude** command.



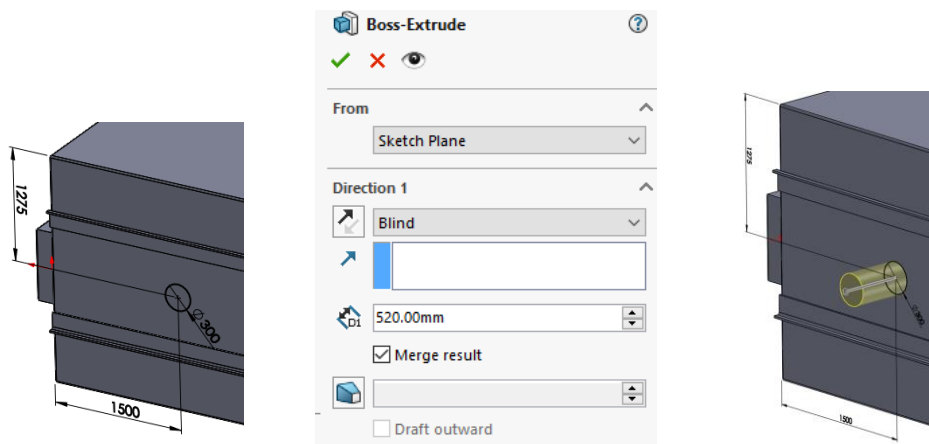
18. Rounding the edges of the storage space

From the **Features** toolbar, select the **Fillet** command. The indicated edges are selected and rounded to a radius of 20 mm.



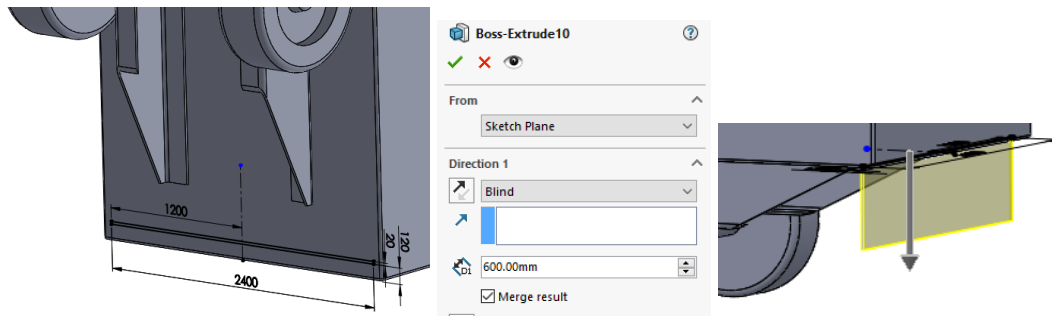
19. Modeling the wagon connection joint

On the underside of the wagon, draw a circle with a diameter of 300 mm from the **Sketch** toolbar. From the **Features** toolbar, the sketch is extruded using the **Boss-Extrude** command to 520 mm.



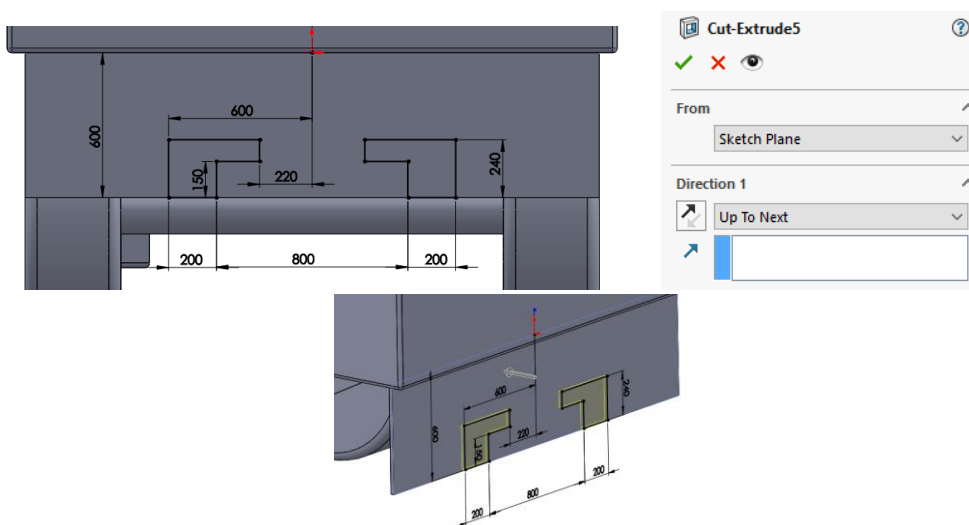
20. Modeling the wagon's illumination panel

On the surface of the wagon at the rear, a rectangle 2400 mm long and 20 mm wide is drawn from the **Sketch** toolbar. This is positioned according to the image below. This tool is extruded using the **Boss-Extrude** command over 600 mm.



21. Cutting out the sign panel

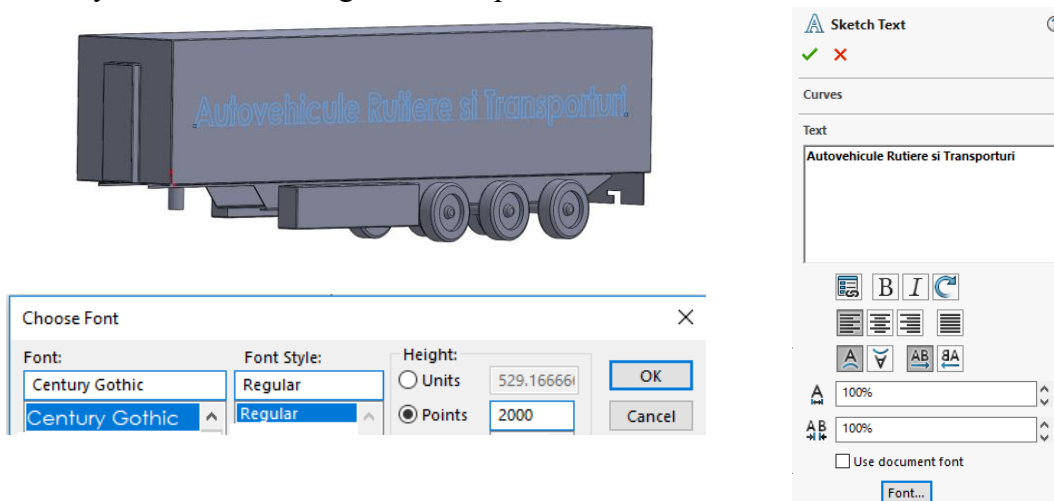
On the surface of the **Sketch** toolbar's signal panel, a sketch is drawn according to the image below. This sketch cuts out the surface from the sign panel. From **Features** tab is cut with the **Cut-Extrude** command to 600 mm.



22. Text inscription on the outer surface of the wagon

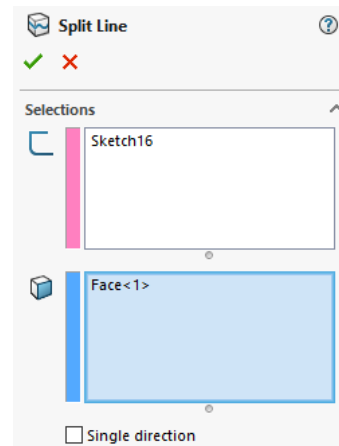
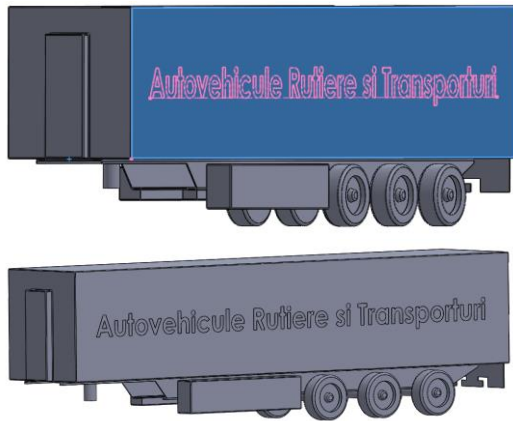
A center line is drawn on the outer surface of the wagon from the **Sketch** toolbar.

From the **Sketch Text**  command, type the text "*Road Vehicles and Transport*" from the keyboard and select the center line. The text will be positioned on this center line. From **Font...** you choose the font type and size; in this case the font is: Century Gothic with a height of 2000 points.



23. Printing text on the wagon surface

Features toolbar, the **Curves** submenu opens, and the **Split Line**  **Split Line** command is selected. The text sketch and the wagon surface to be printed on are selected, as shown in the images below.

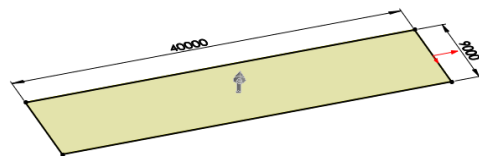
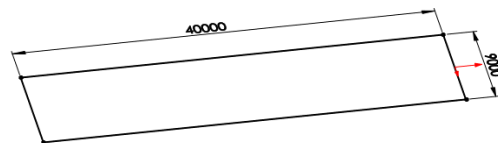
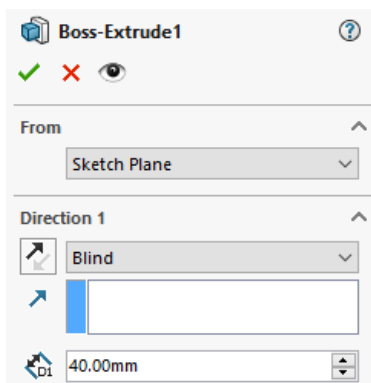


Road modelling

1. A new part file is opened.

Road modelling

From the **Sketch** tools, draw a rectangle whose origin is in the middle of the width.



Assembly modelling

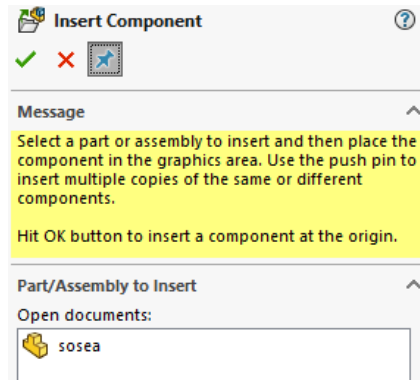
1. A new assembly file is created
2. A new part file is opened.

The road is introduced from the tool palette

via the **Insert Component**

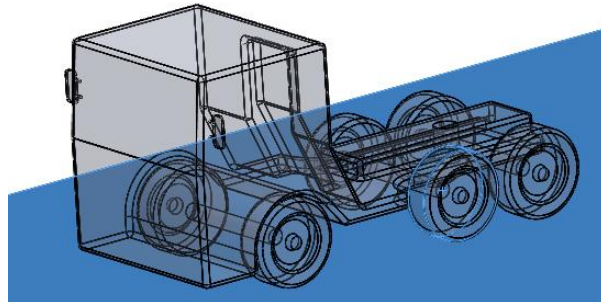
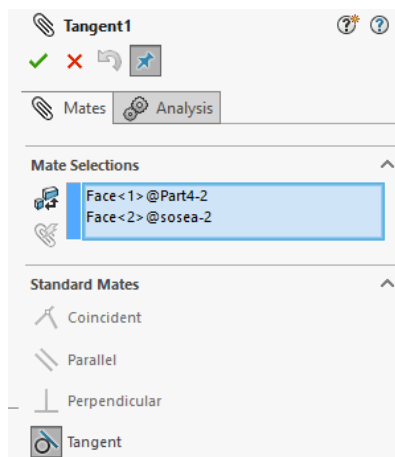


command. The **Keep Visible**  button is activated to enter the road model relative to the assembly's coordinate system.

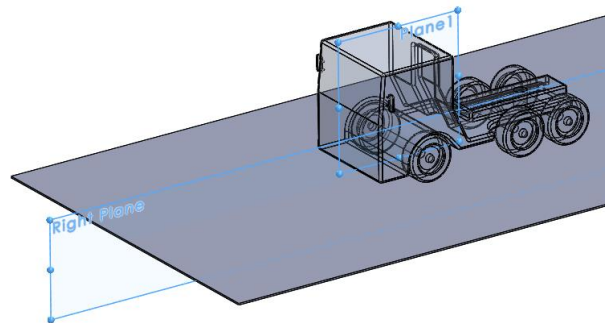
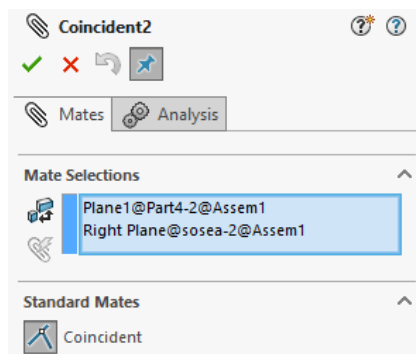


3. Insert the truck cabin into Assembly

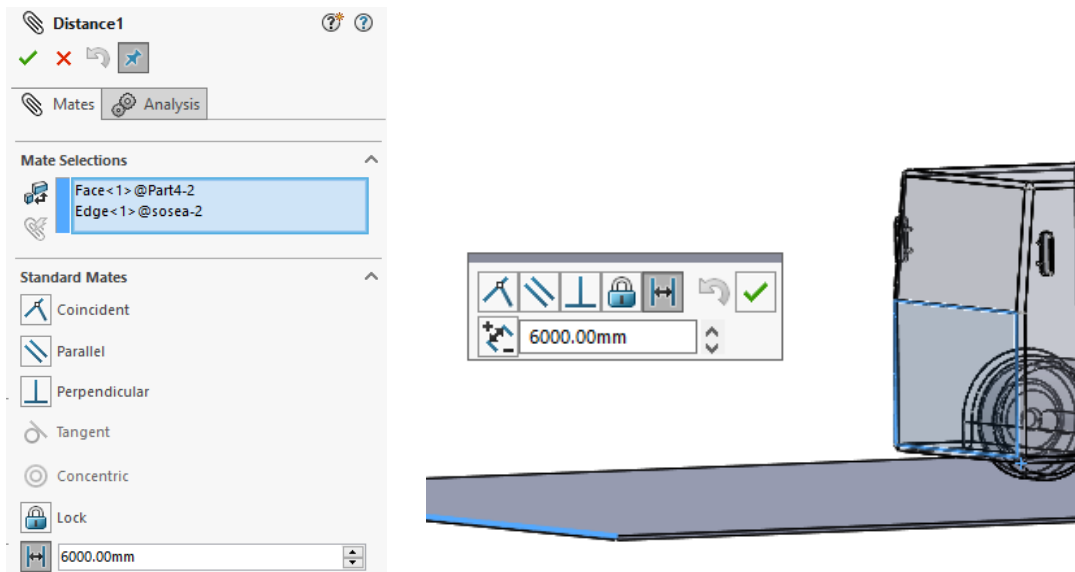
You just assemble the tools through the **Mate**  command, and one of the wheels is positioned tangent to the road surface, as shown in the image below.



The median plane of the tractor head and that of the road are positioned coincidentally using the **Mate** command.

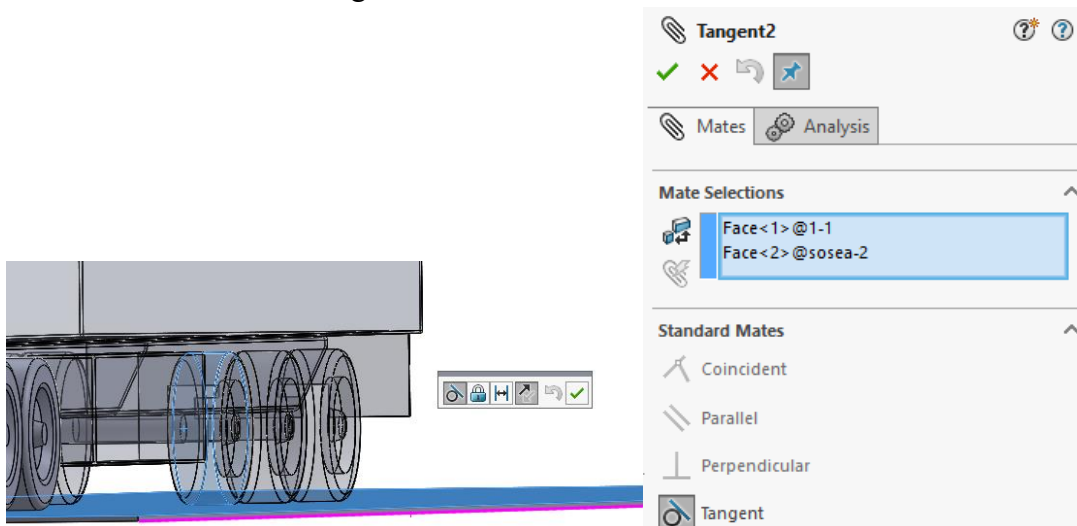


The front surface of the cabin is positioned 6000 mm from the end surface of the road model, as shown in the image below.

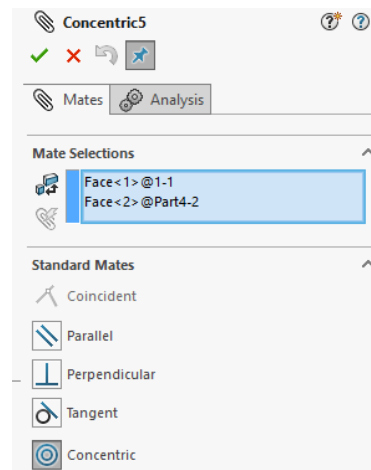
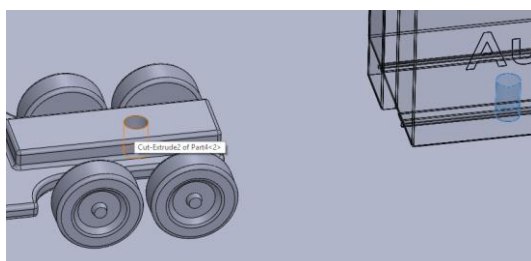


The trailer model is introduced into the assembly.

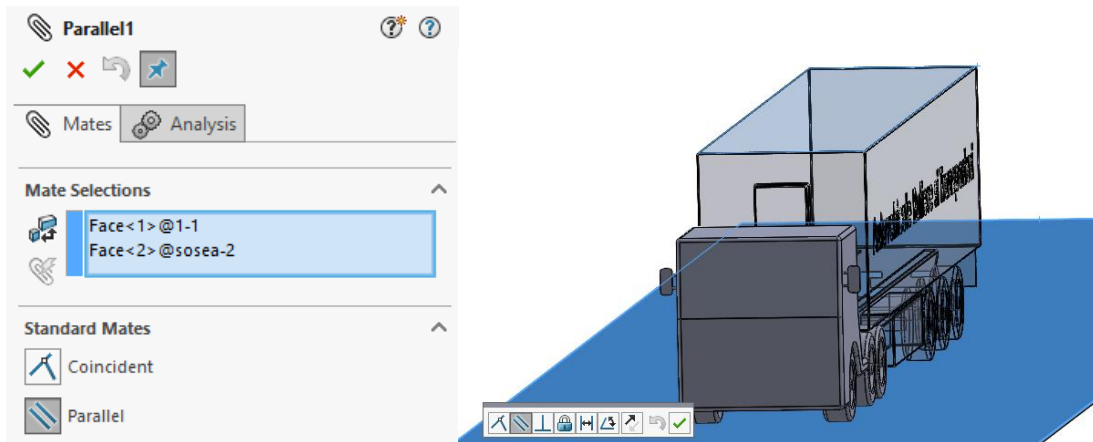
One of the trailer wheels is positioned tangent to the road surface via the **Mate** control, as shown in the image below.



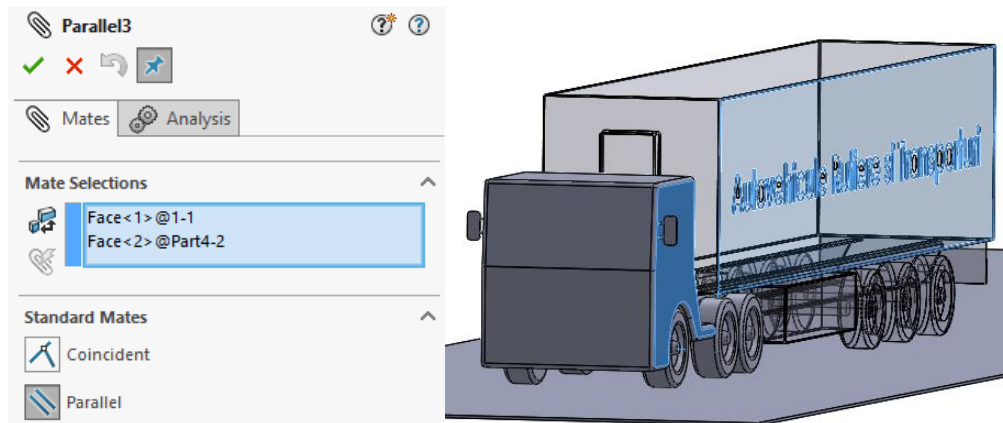
By selecting the cylindrical surfaces indicated in the image below and choosing a **Concentric Mate**, the trailer is assembled to the tractor unit.



The upper surface of the trailer is positioned parallel to the road surface by choosing a **Parallel Mate**.

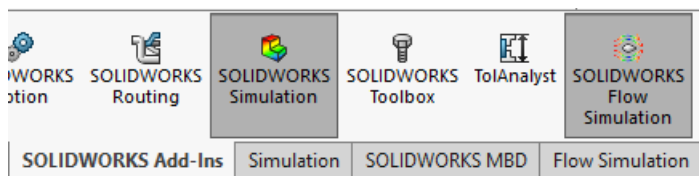


The side surfaces of the tractor and trailer are aligned using a **Parallel Mate**.

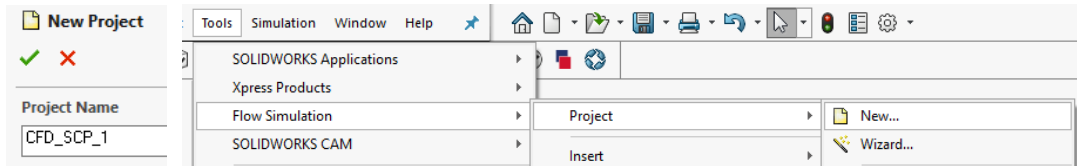


II. Performing the CFD simulation

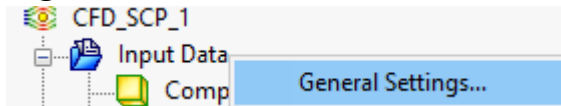
The **SolidWorks Flow Simulation** module is activated from the SolidWorks **Add-Ins** toolbar.



From the **Tool** menu, a new project is created and named, as shown in the image below.

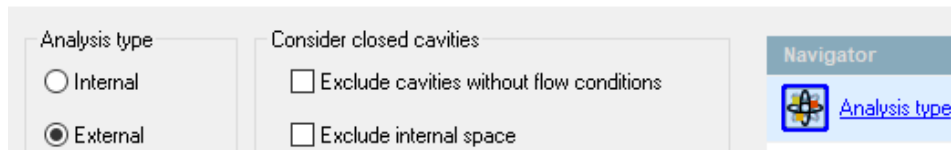


The general simulation settings are chosen by right-clicking on **Input Data, General Settings...**

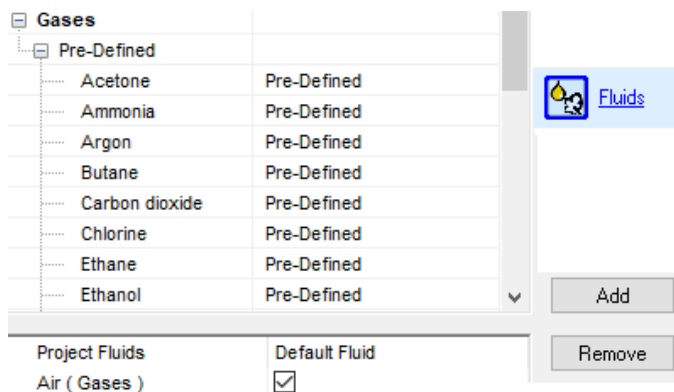


The analysis type is selected – External

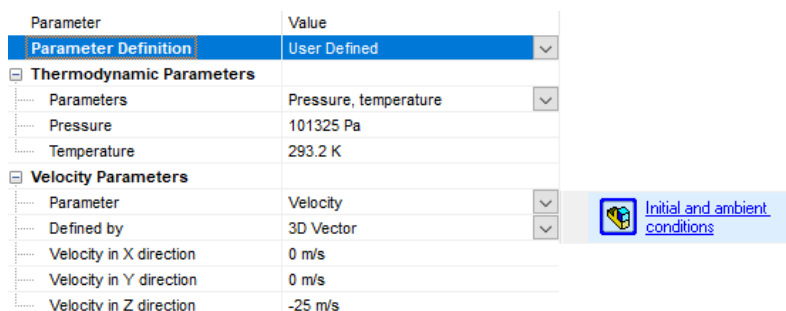
General Settings



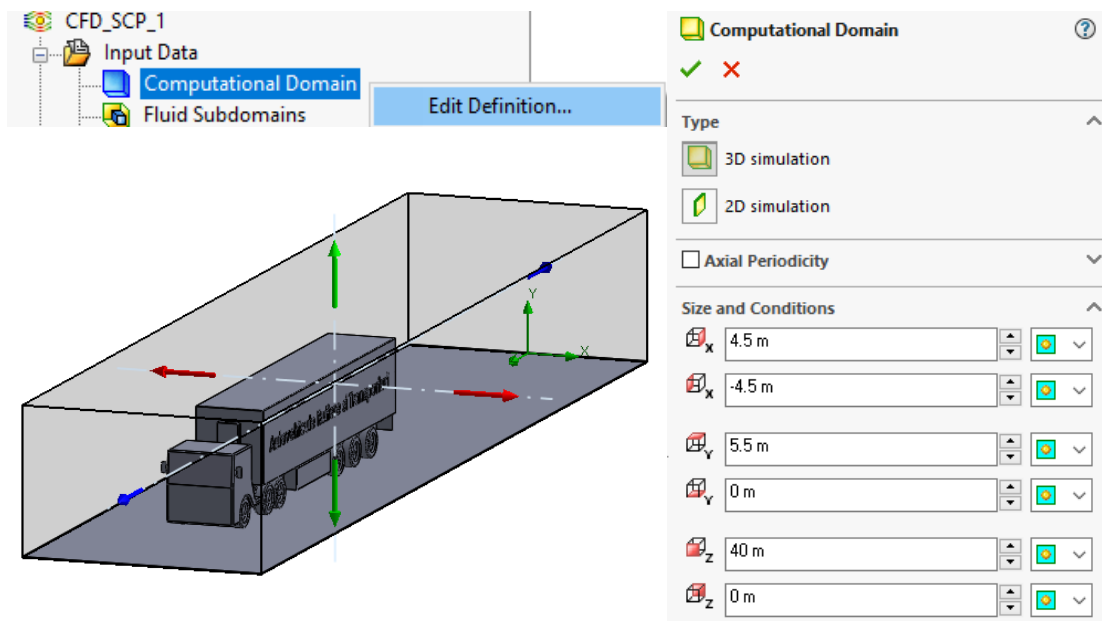
The fluid for the simulation is chosen, which is air.



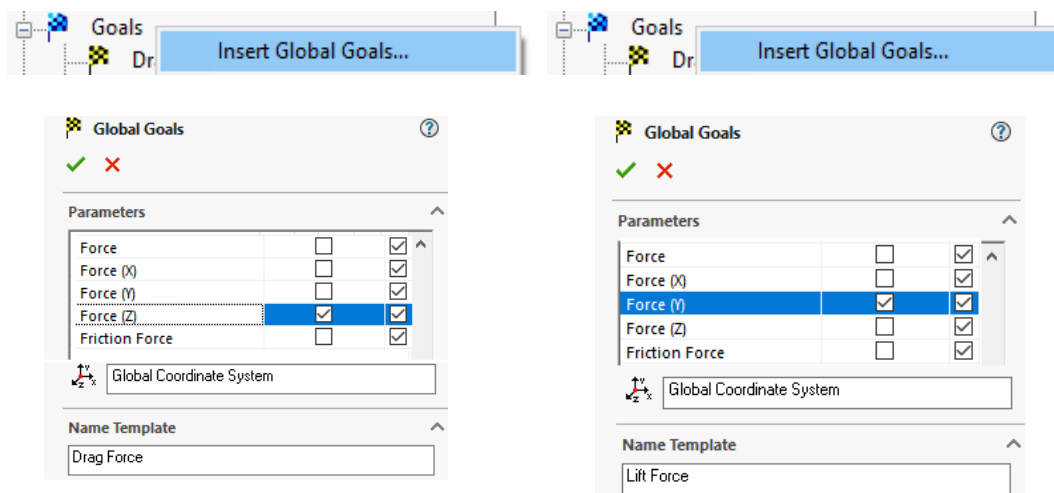
An air velocity of 25 m/s in the direction opposite to the forward motion is required.



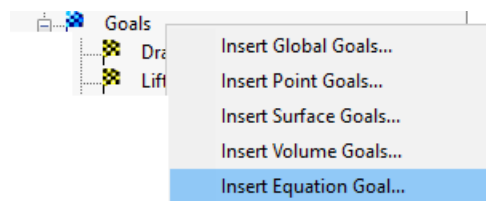
By right-clicking, **Edit Definition...** defines the calculation domain, as shown in the images below.

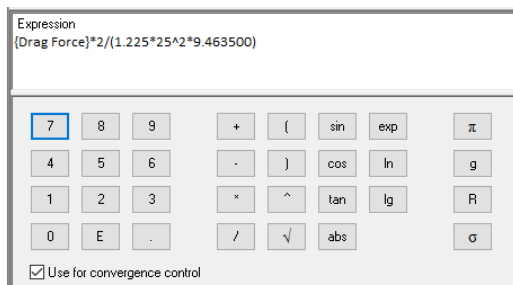


Inserting objectives is done by right-clicking on **Goals** and opening **Insert Global Goals...**



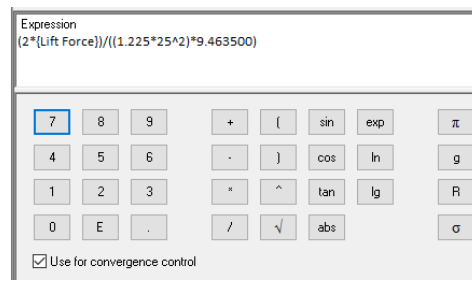
The determination of the drag coefficient and the lift coefficient is done by selecting **Insert Equation Goal...** The expression of these coefficients is entered manually from the keyboard, based on the formulas and values of the coefficients presented in the first part.



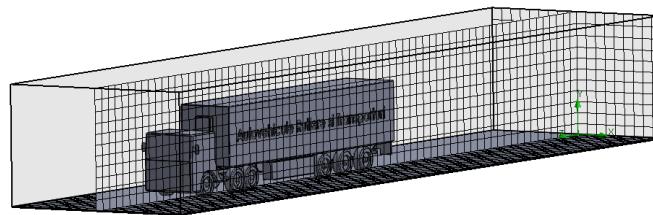
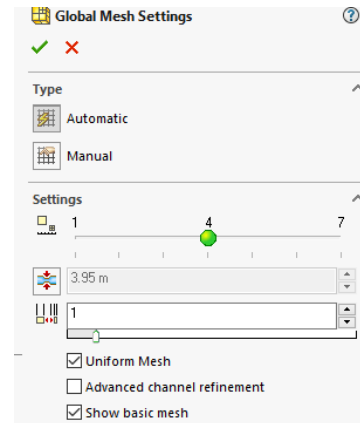
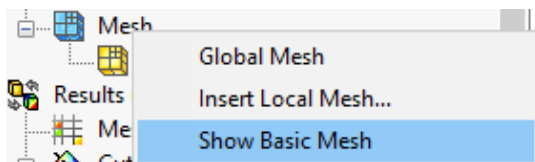


$\{ \text{Drag Force} \} * 2 / ((1.225 * 25^2 * 9.463500))$

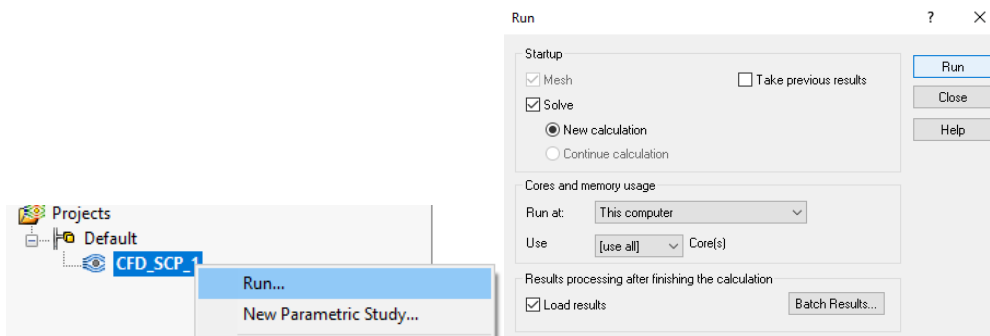
The size of the discretized elements is chosen according to the images below.



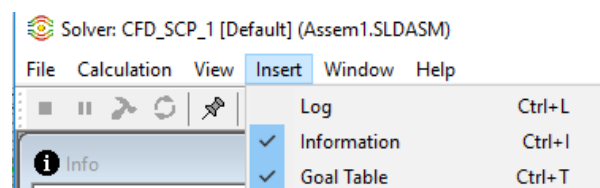
$(2 * \{ \text{Lift Force} \}) / ((1.225 * 25^2) * 9.463500)$



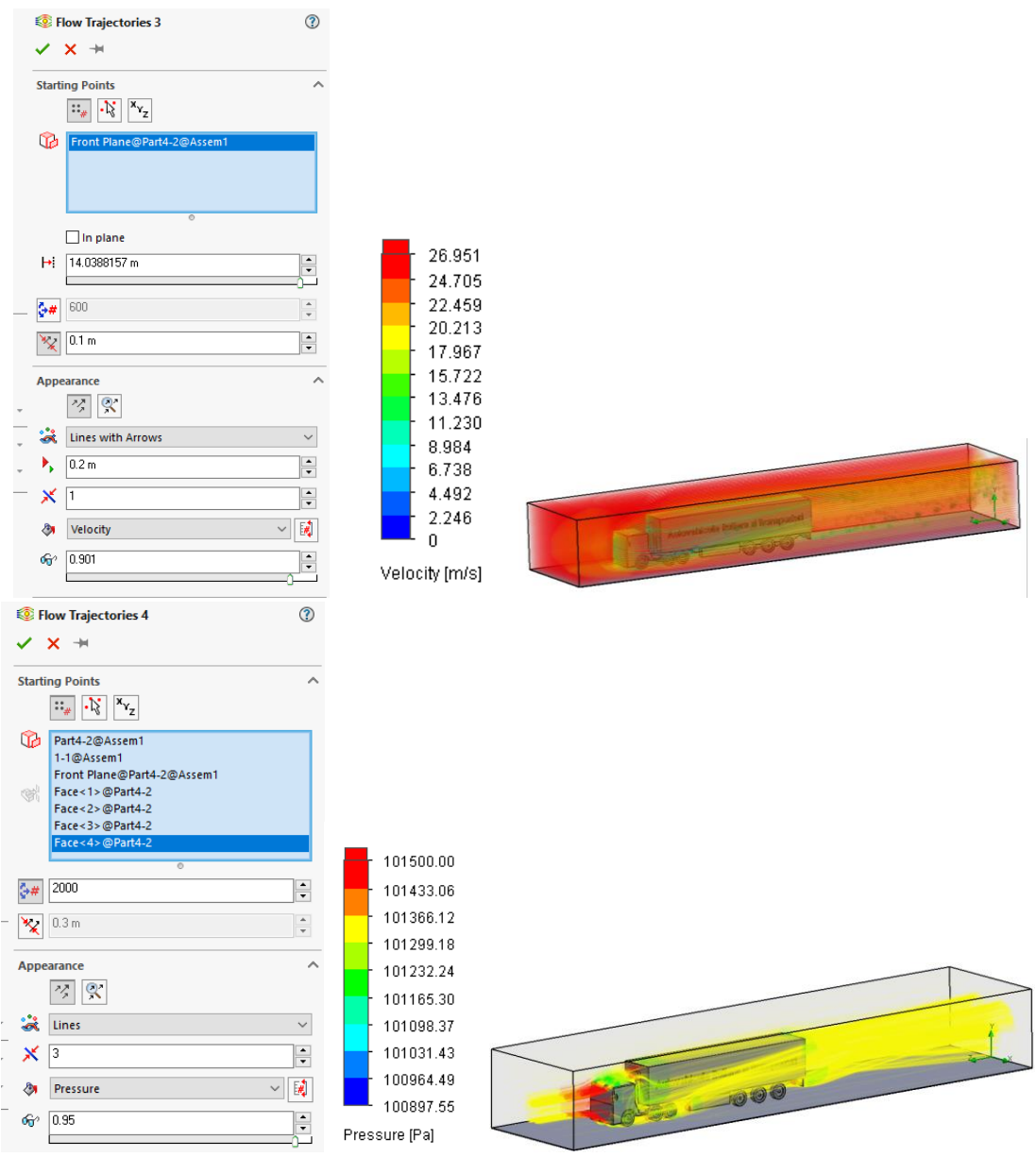
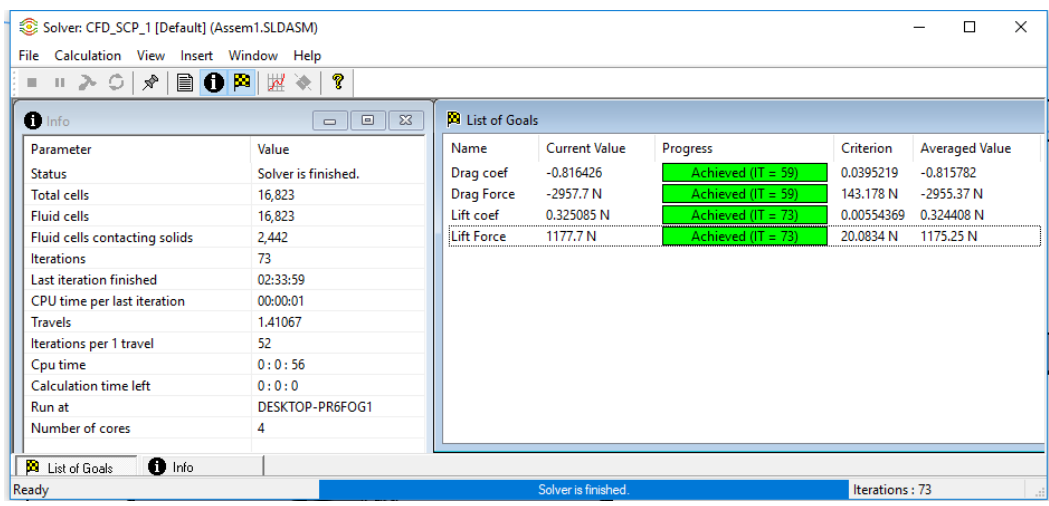
By right-clicking on the created project, you select "**Run...**", and then in the dialog box that opens, you run the simulation by clicking the "**Run**" button.

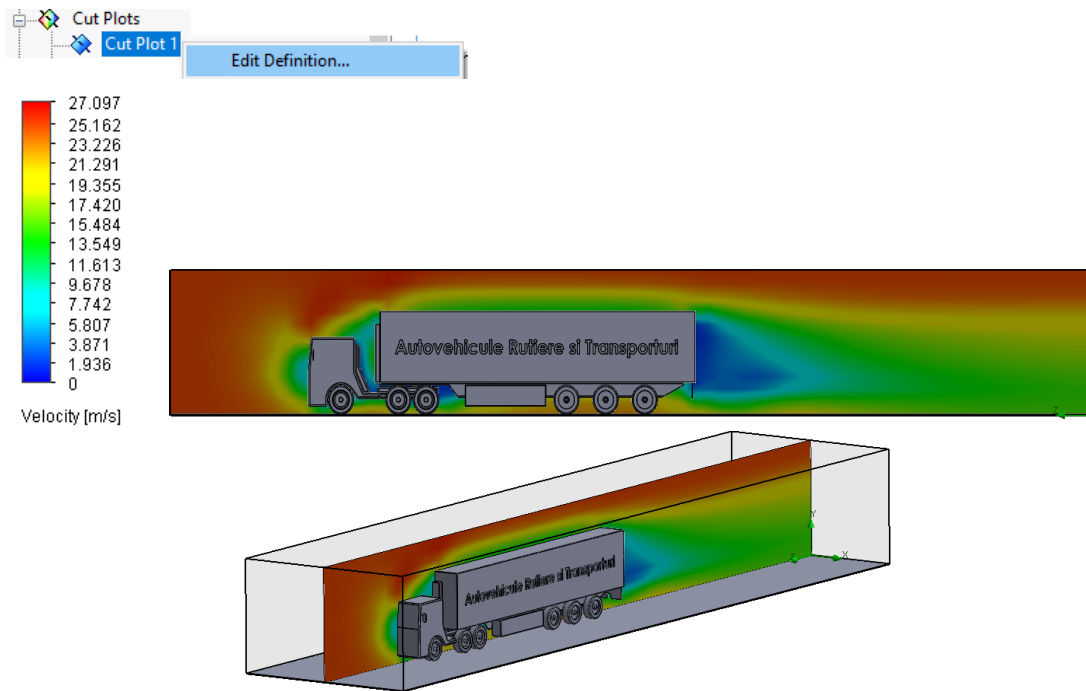


Visualization of simulation-related information can be activated from the Insert menu by checking the Information and **Goal Table** options.



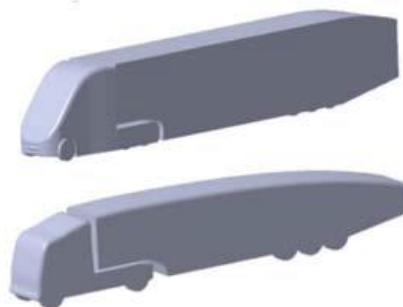
Results





III. Self- evaluation test

1. Mount an air deflector on the cabin roof and restart the simulation. What are the aerodynamic improvements made to the road train?
2. Simulate the aerodynamic characteristics of the tractor head.
3. Model and simulate a road train according to the examples below and comparatively analyze their dynamic performance.



4. Introduce the following aerodynamic performance enhancement devices into the semi-trailer construction and analyze their effect.



	Cd	Cl	Obs.
V1-base			
V2-improved Air deflector mounted on cab			
V2-improved Air deflector mounted on rear side of the trailer			