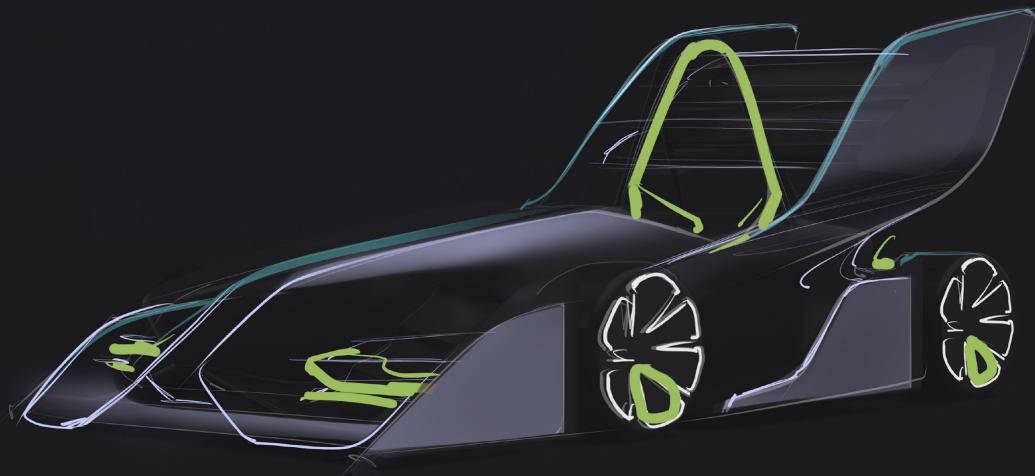


# Formula Student





# Skoltech Racing



**15 people**



**6  
mentors**



**8 subteams**



**1000  
hours**



**1 goal**

## Introduction to PLM



Teams assembly



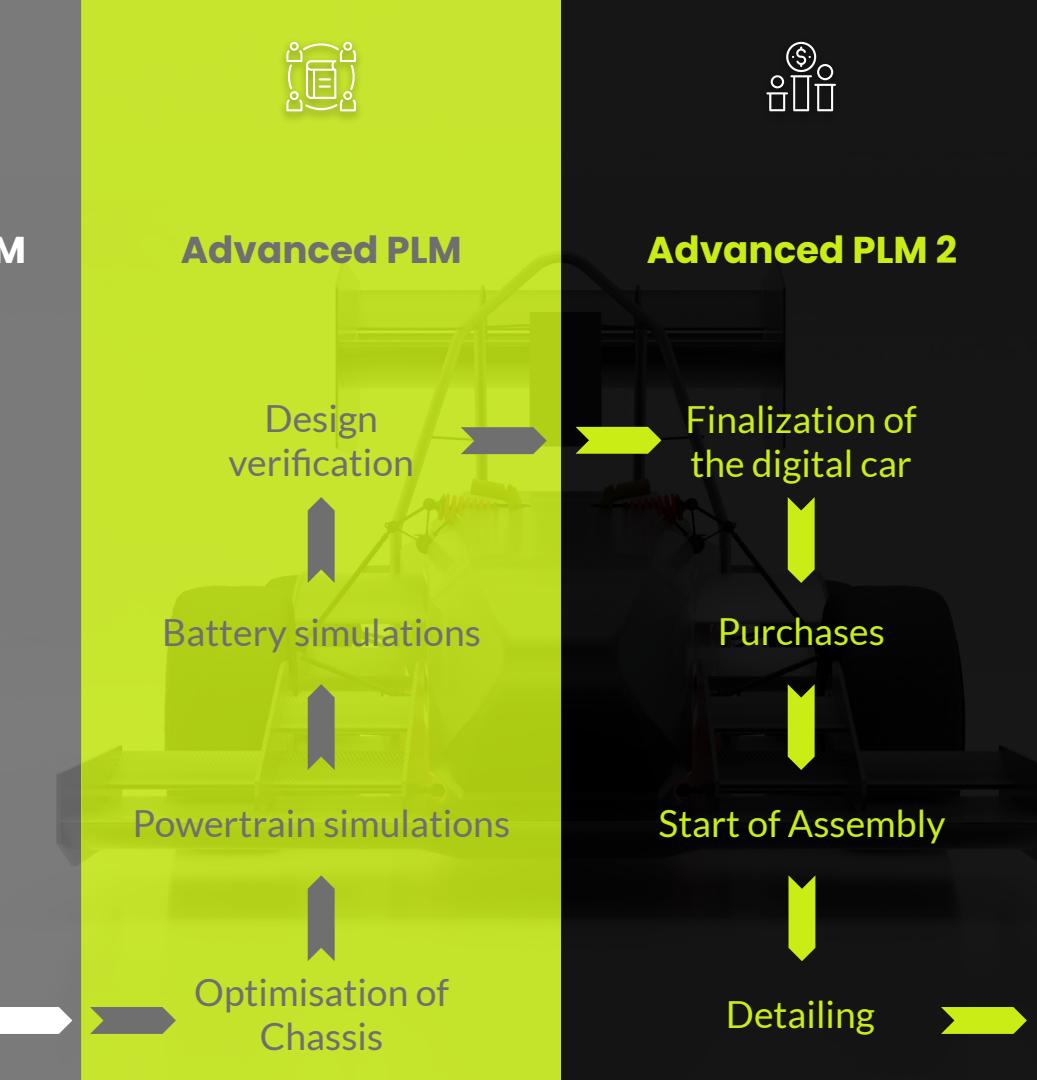
Rules management



Simulations



First digital twin



## Assembly & Racing

Racing



Adjustments



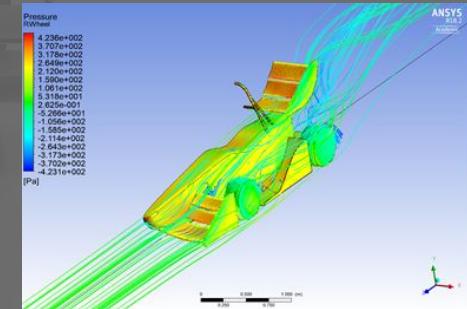
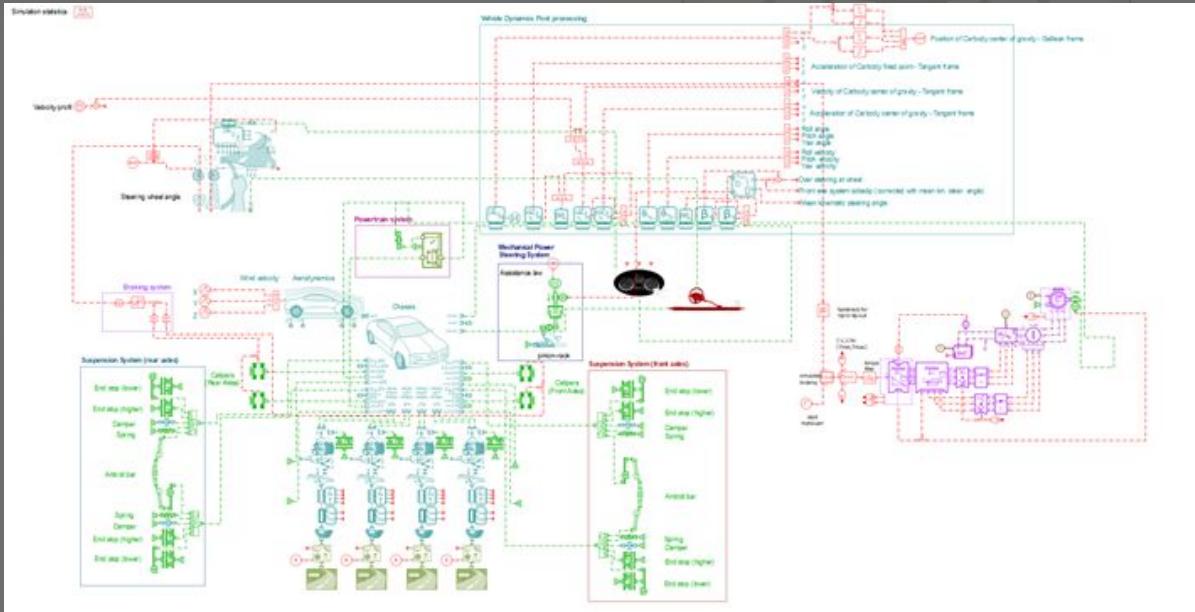
Testing



Assembly

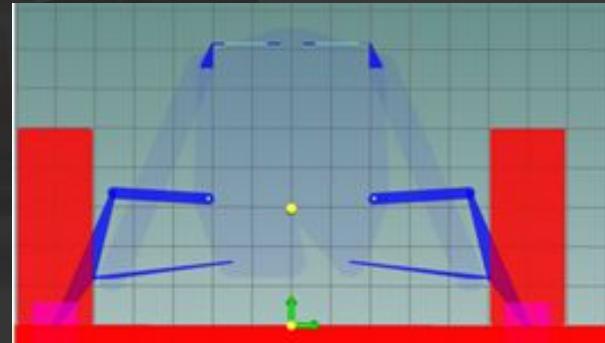
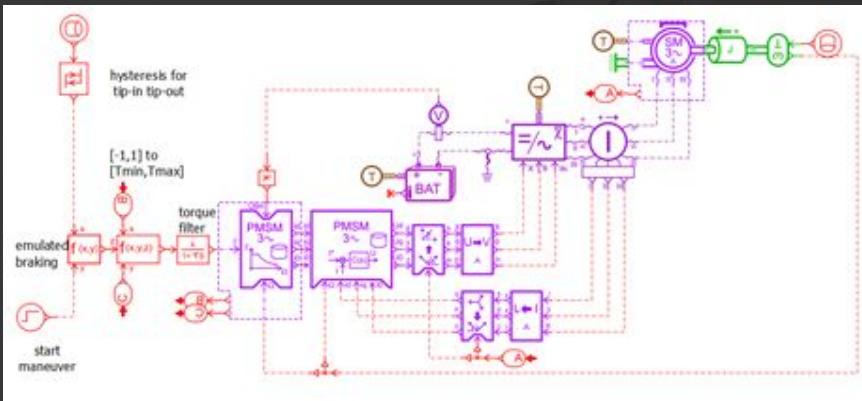
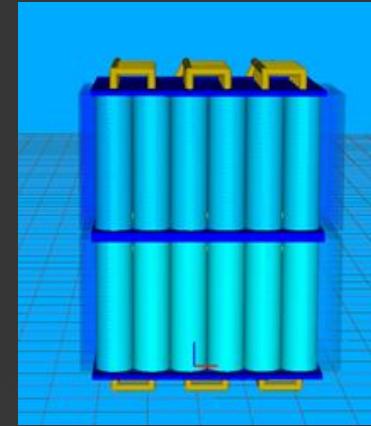
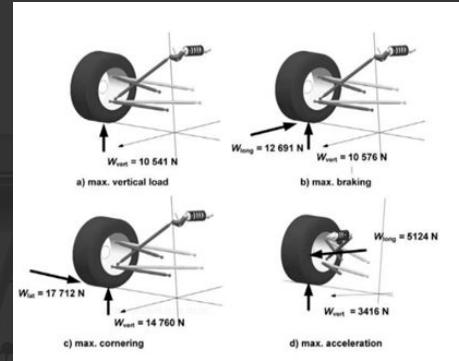
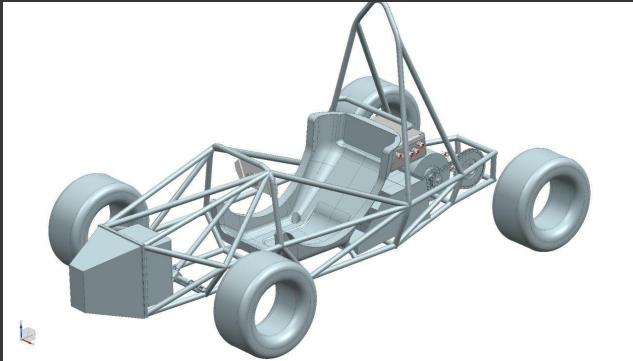


# Introduction to PLM





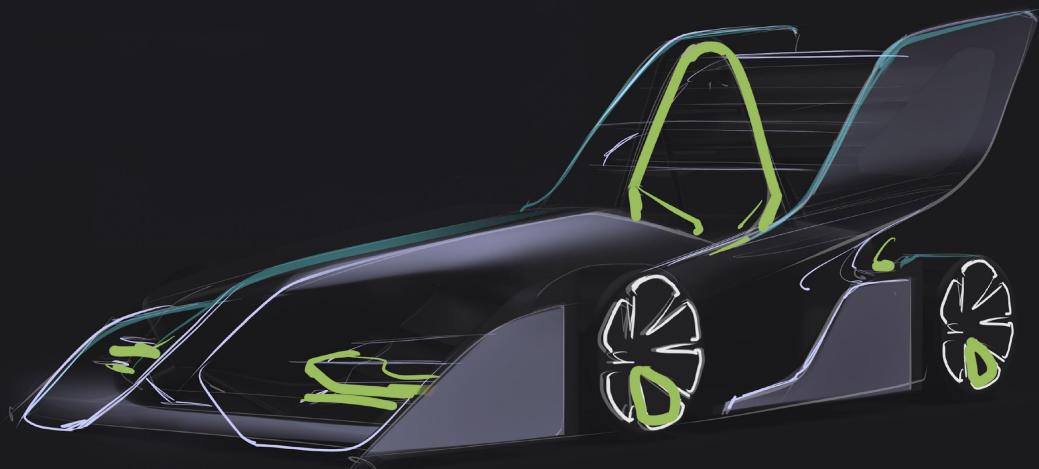
# Advanced PLM



# Highlights of today

- Possible designs
- Manufacturing plan
- Detailed design and preparation to manufacture:
  - Chassis
  - Powertrain supports
  - Electronics and energy storage
  - Car controls
  - Hub unit
- Verification system

Initial design



Collaborative design

РЕНДЕР



РЕНДЕР



РЕНДЕР



Timur Dautov

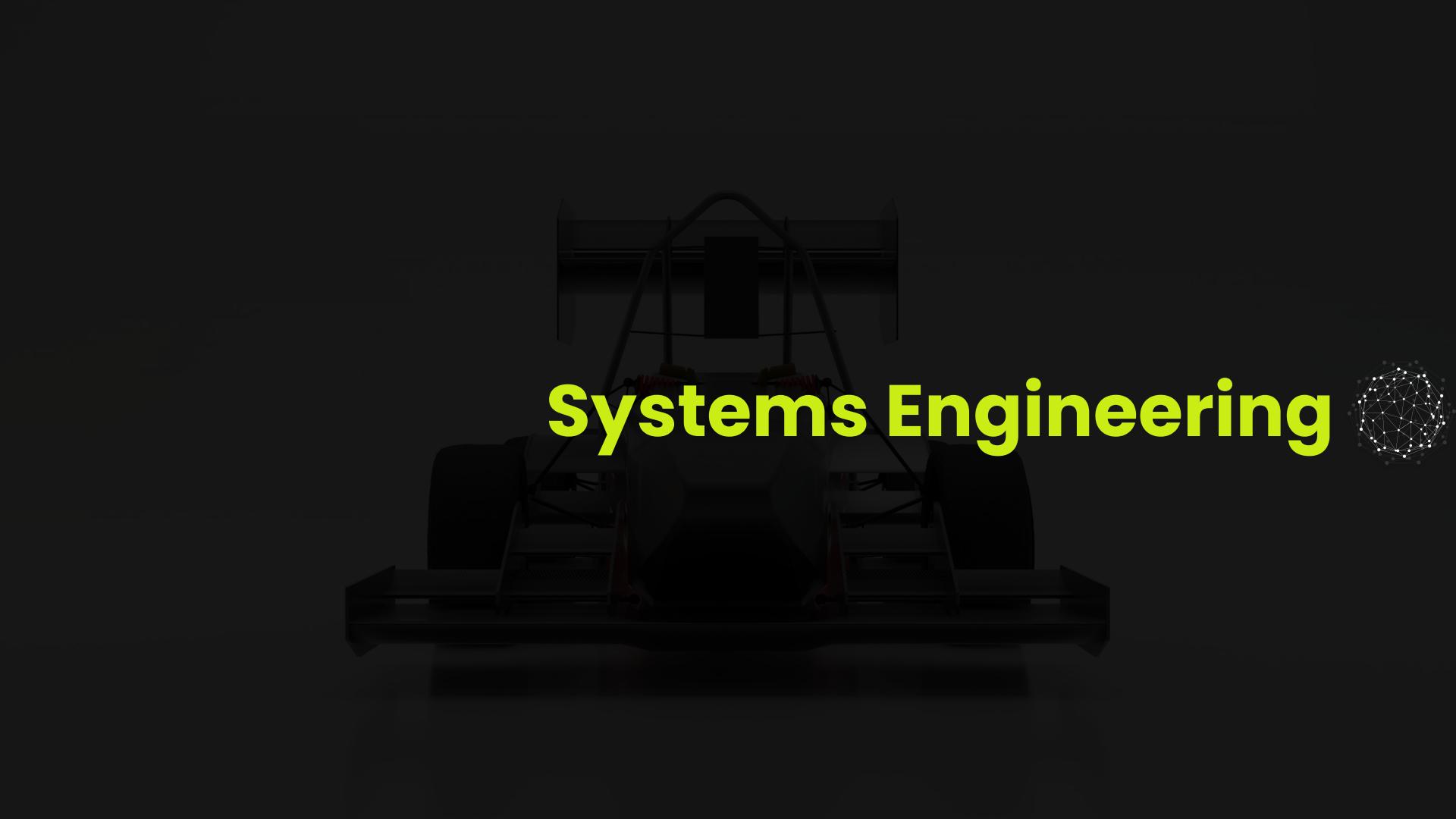




Arslanova L.



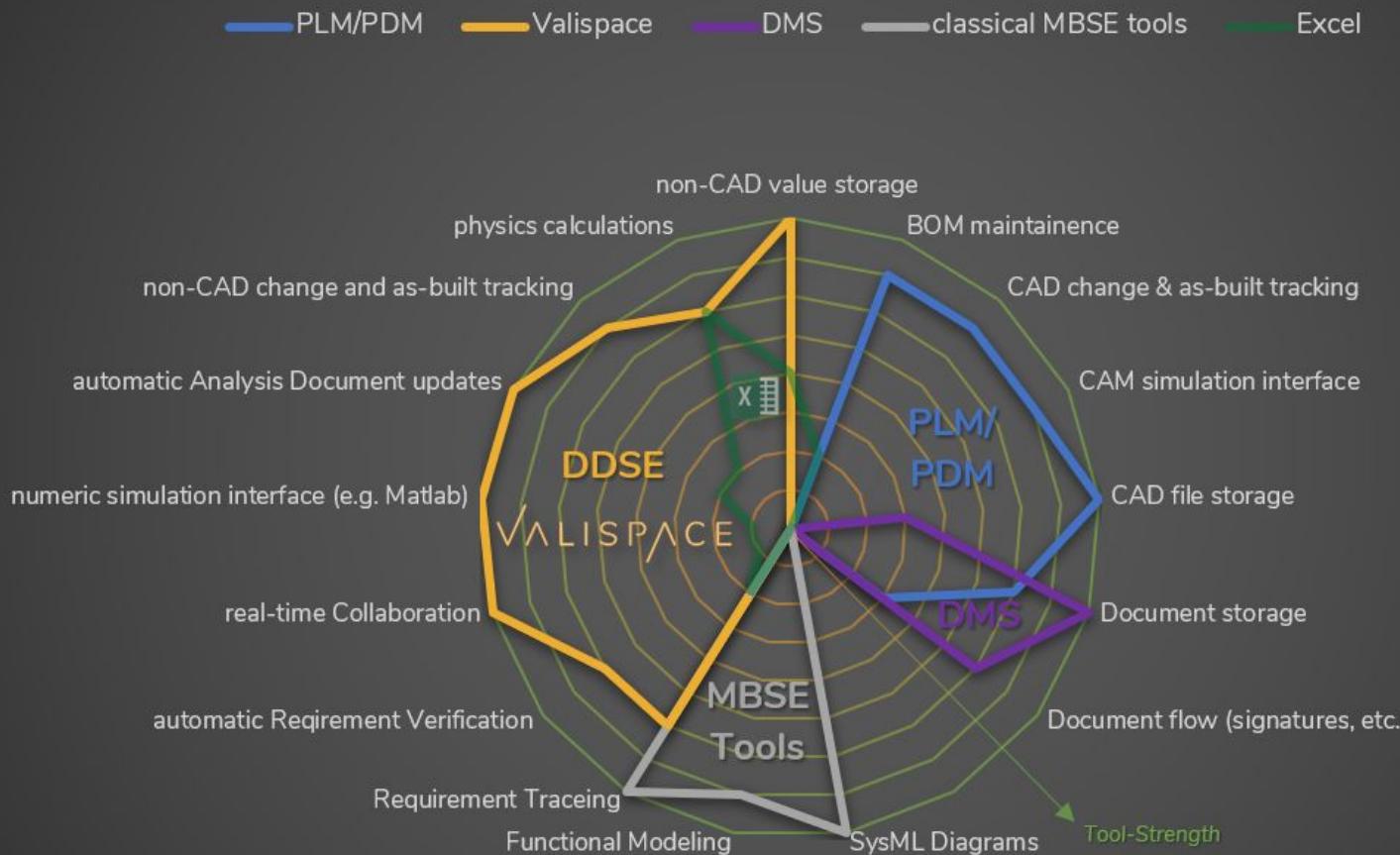
moscow  
polytech



# Systems Engineering



# Tool Strengths and Complements



# Products used:

TEAMCENTER

VALISPACE



Project



Google

SIEMENS

DS SIMULIA  
Abaqus



Excel

SIEMENS NX



DS SOLIDWORKS

# Versions control and verification

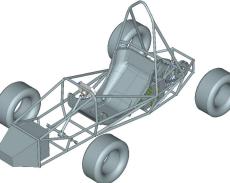
## Modelling

▼ PROPERTIES

ID:	FS.00.00
Name:	Car assembly
Description:	Whole car assembly, which includes all subsystems
Type:	Assembly
Release Status:	
Date Released:	
Effectivity:	
Owner:	Evgeniy Naumenko (e.naumenko)
Group ID:	Formula student.Introduction to PLM
Last Modifying User:	Denis Artemov (d.artemov)

▼ GLOBAL ALTERNATES

▼ PREVIEW



PLM type organization

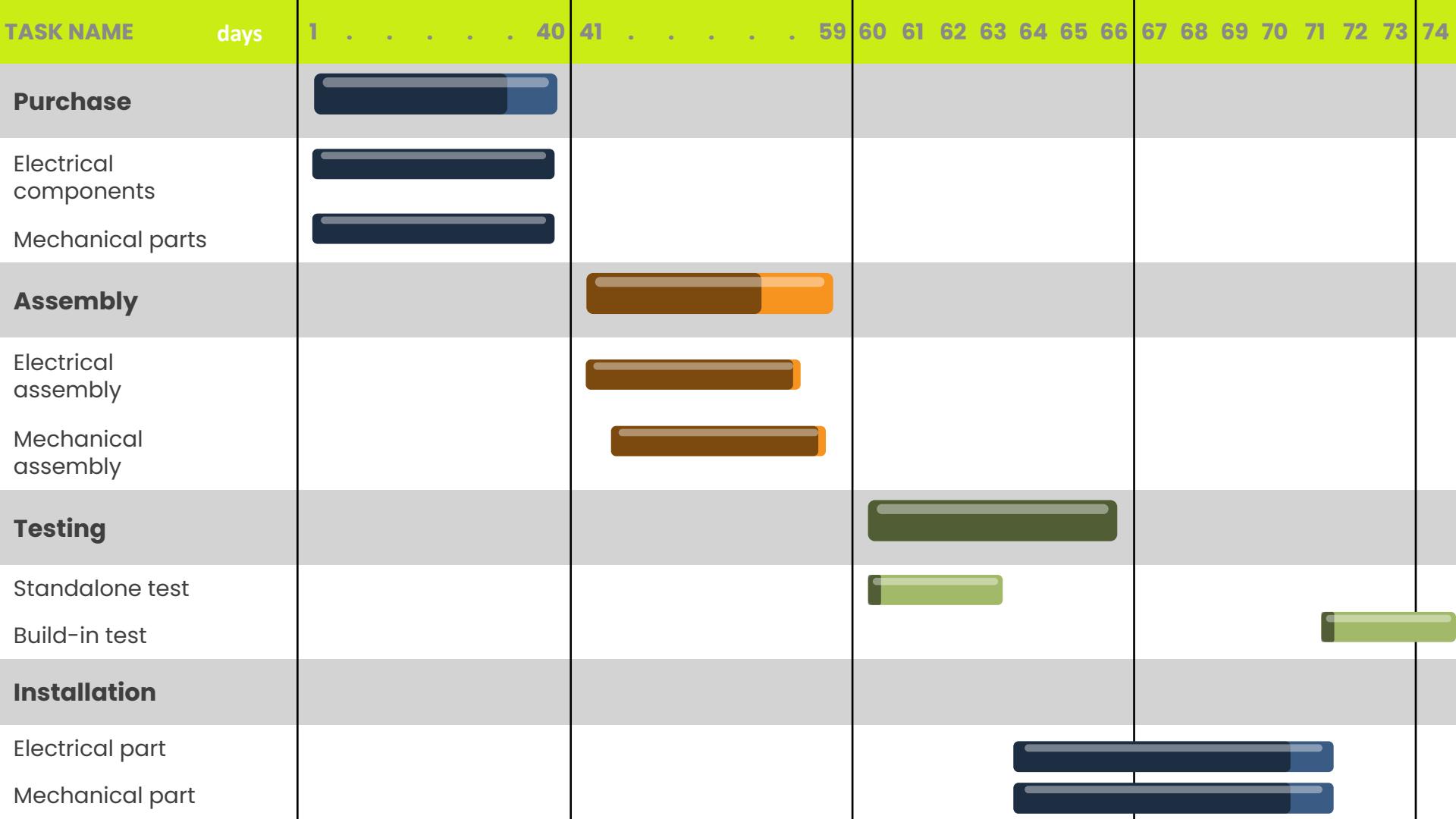
## Verification

Assigned specifications  T3.17\_Impact\_Attenuator.IA 

In order to assign a Requirement to this Component it has to be wrapped into a Specification, which you can then assign above – [Go to Requirements](#)

IDENTIFIER	COMPONENT	REQUIREMENT TEXT	VERIFICATION METHODS	CLOSEOUT REFERENCES	VERIFICATION STATUSES	VERIFICATION COMMENTS	STATUS	CHILDREN	VERIFIED	COMPLIANCE
T3.17.1-453	Impact_Attenuator	Each vehicle must be equipped with an IA.	Inspec...		Verified	IA present	N/A	1/1	N/A	Compliant
The IA must be:										
<ul style="list-style-type: none"><li>Installed forward of the front bulkhead.</li><li>At least 100mm high and 200mm wide for a minimum distance of 200mm forward of the front bulkhead.</li><li>Not able to penetrate the front bulkhead in the event of an impact.</li><li>Attached securely and directly to the Anti Intrusion Plate (AIP).</li><li>Not part of the non-structural bodywork.</li><li>Designed with a closed front section.</li><li>Cannot be wider or higher than the AIP.</li></ul>										
T3.17.2-452	Impact_Attenuator		Review		Not ver...		0/1	N/A		

ValiSpace



## Manufacturing plan

- More than 120 tasks and sub-tasks
- 6 month - required time
- More than 2 200 man-hours required
- 350 man-hour for testing
- 30 people team

## Budget estimates\*

Car part	Costs, rubs
Chassis	279 026 ₽
Powertrain	2 148 576 ₽
Bodyframe	1 026 000 ₽
Brake system	278 625 ₽
Steering system	855 633 ₽
Suspension	1 498 396 ₽
	<b>≈6 000 000 ₽</b>

\*only manufacturing included



# Components



# Overall look

Body Kit Parts

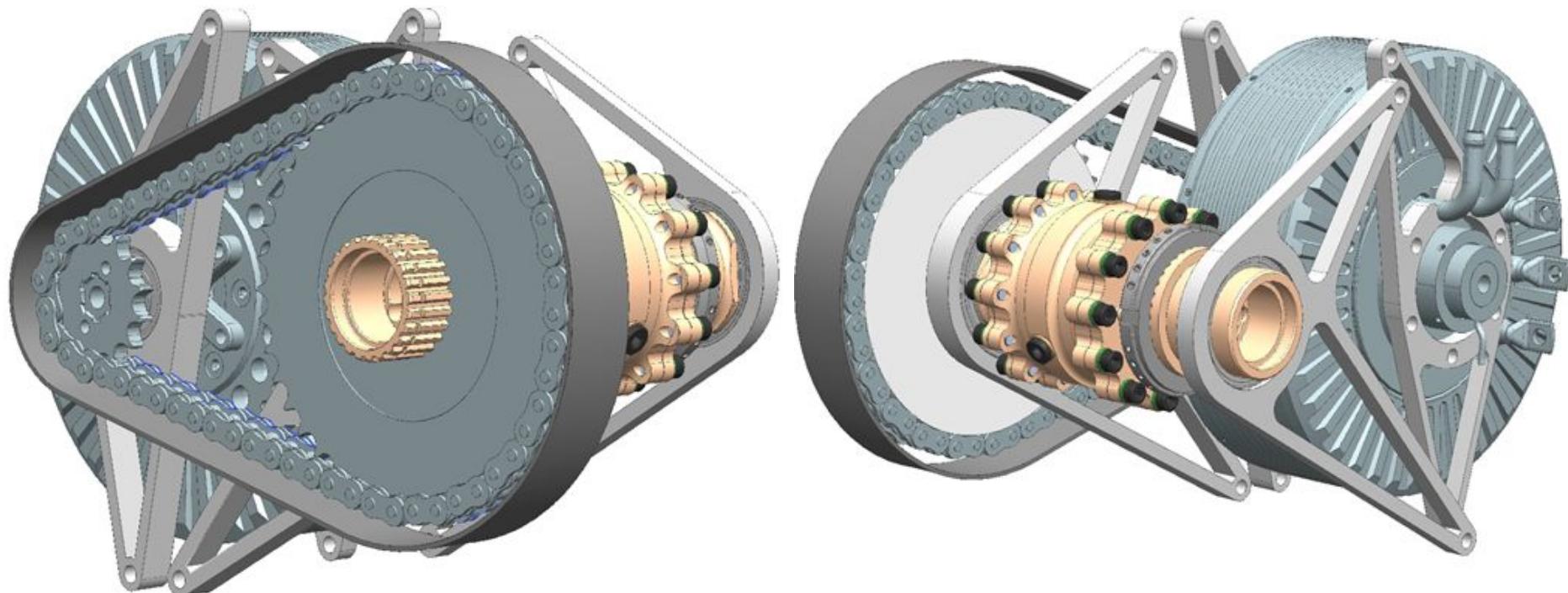


# Overall look

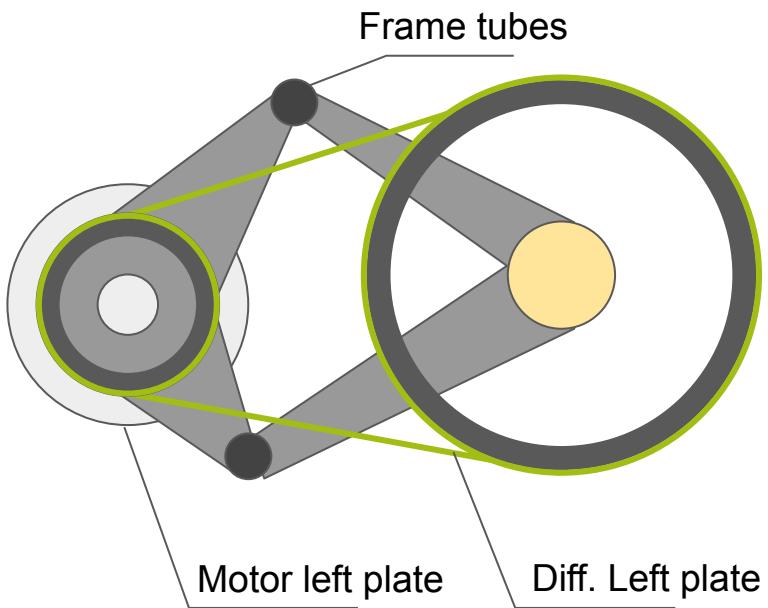
Inner assembly



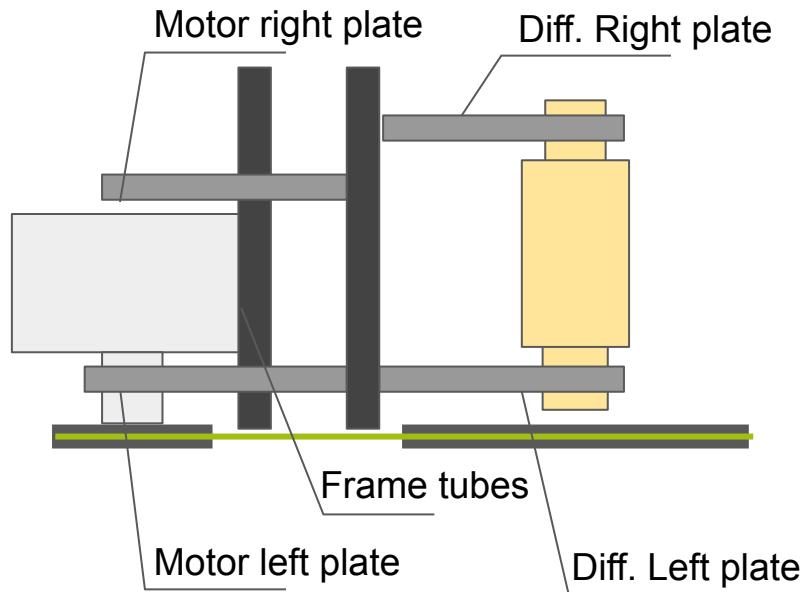
# Powertrain



# Transmission Scheme

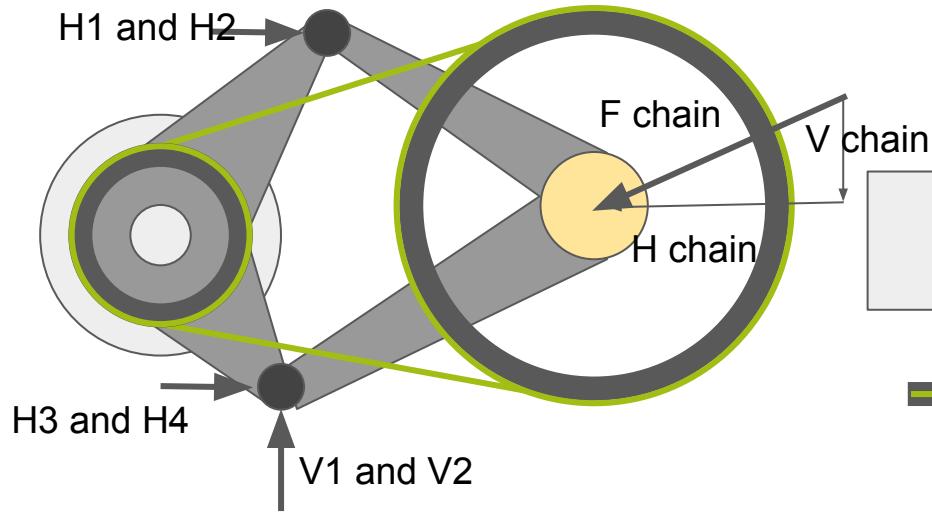


Side View

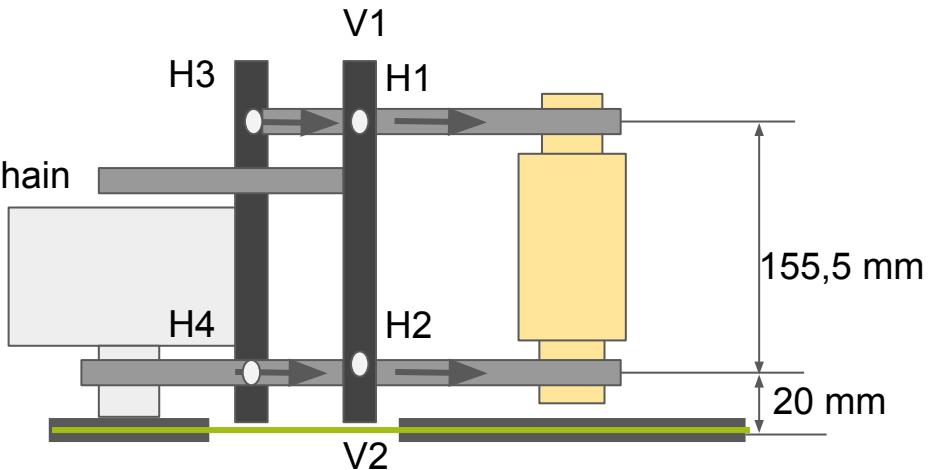


Top View

# Transmission Scheme

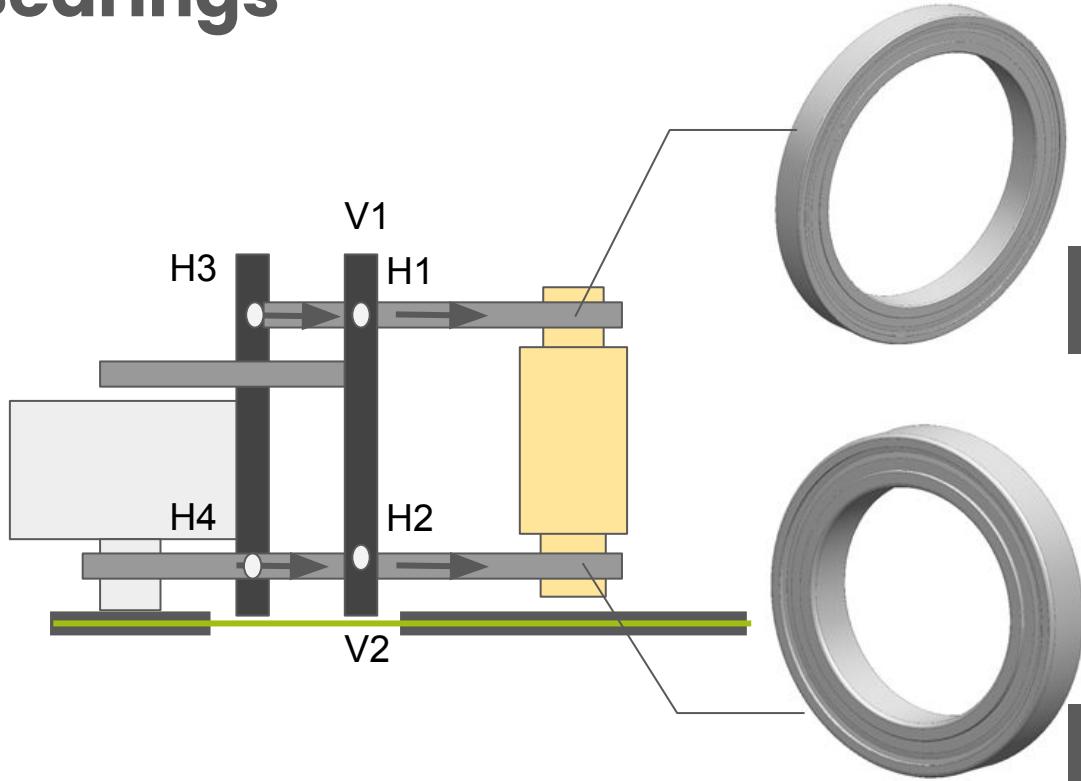


Side View



Top View

# Bearings



61810-2RZ:

- Dimensions: 50x65x7 mm;
- Mass: 0,053 kg;
- Limiting speed: 10000 r/min;
- Basic dynamic load rating C: 6.76 kN;
- Basic static load rating C0: 6,8 kN.

Bearing 1 calculated load: 1,2 kN

61911-2RZ:

- Dimensions: 55x80x13 mm;
- Mass: 0,19 kg;
- Limiting speed: 8500 r/min;
- Basic dynamic load rating C: 16.5 kN;
- Basic static load rating C0: 14 kN.

Bearing 2 calculated load: 11 kN

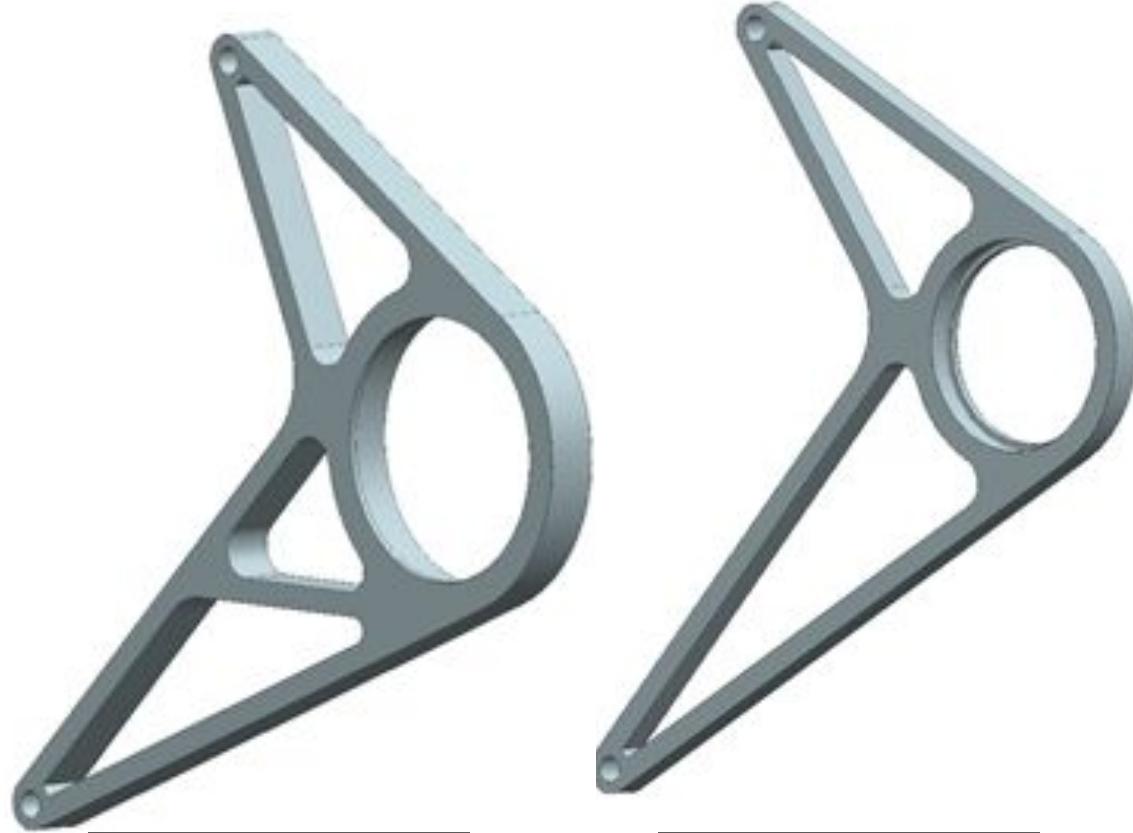
# Geometry

Selected material: D16T  
(duralumin) analog -  
2024 T3511

Density: 2,78 g/cm<sup>3</sup>

Yield strength: 300 MPa

Young`s Modulus: 6900  
kg/mm<sup>2</sup>

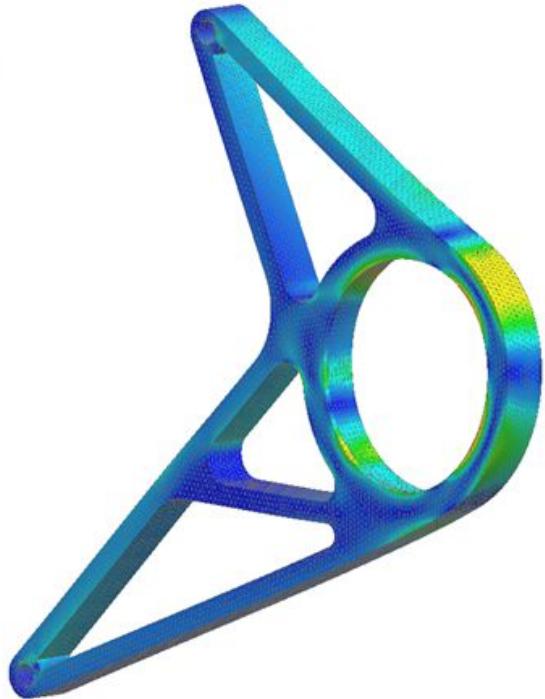


Mass: 0.3 kg

Mass: 0.177 kg

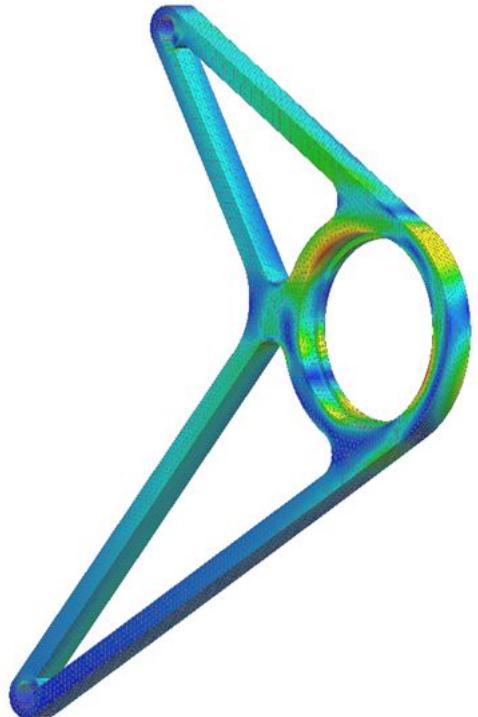
# FEA analysis

FS E 04.05 sim2\_00 : Soln 1 Result  
Subcase - Static Loads 1, Static Step 1  
Stress - Element-Nodal, Unaveraged, Von-Mises  
Min : 0.08, Max : 202.59, Units = MPa  
Deformation : Displacement - Nodal Magnitude



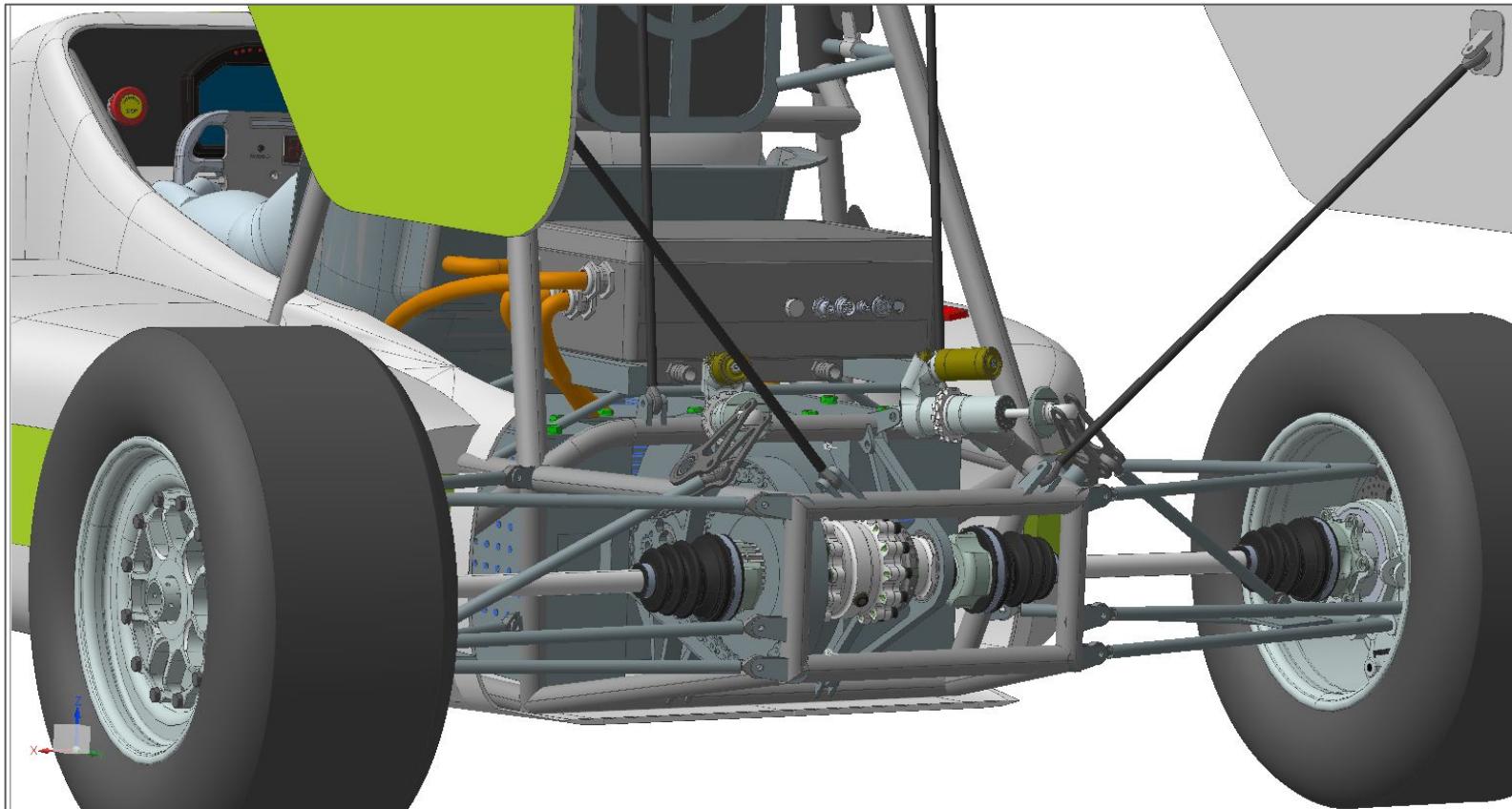
FoS: 1,6

FS E 04.06 sim1\_00 : Soln 1 Result  
Subcase - Static Loads 1, Static Step 1  
Stress - Element-Nodal, Unaveraged, Von-Mises  
Min : 0.04, Max : 24.45, Units = MPa  
Deformation : Displacement - Nodal Magnitude

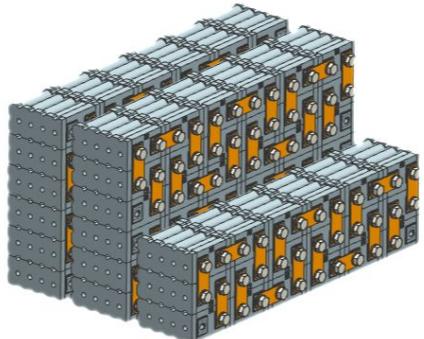


FoS: 15

# Preallocation of elements

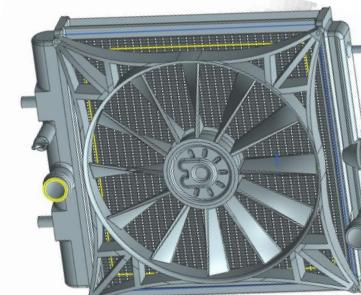
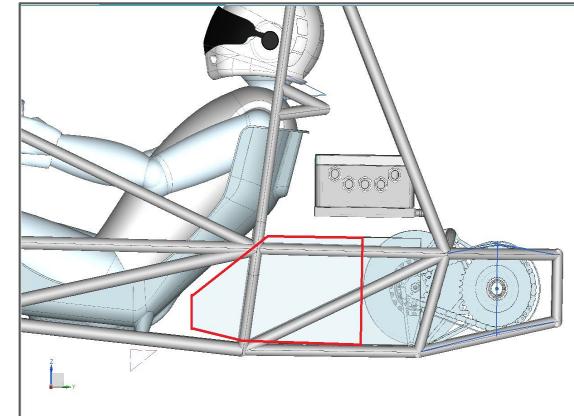


# Battery layout and cooling components



**Size**

Length : 290 mm  
Height : 240 mm  
Width : 425 mm



# Battery CFD Analysis

Velocity of air inlet = 1.4, CFM

Power = 40, W

Heat transfer coefficient = 30, w/m K

Thermal conductivity = 0.66, w/m K

Specific heat = 740, J/kg K

Density = 2.3E-9, kg/ m<sup>3</sup>

Initial data

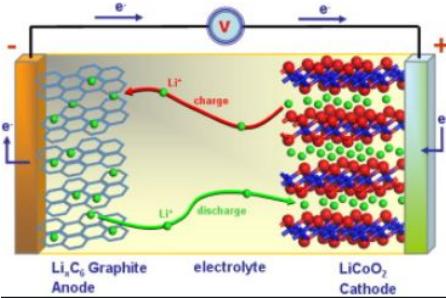
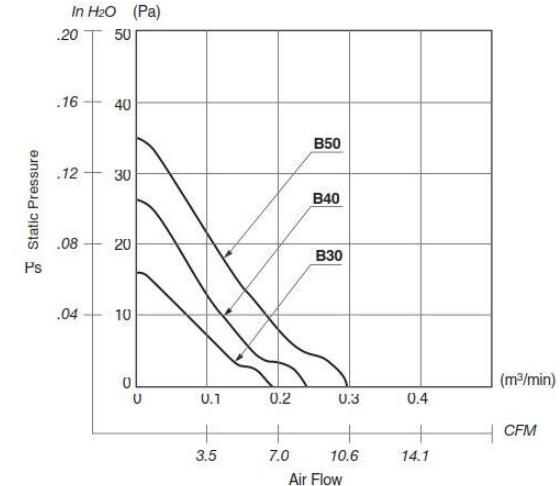


Table 4. Thermophysical properties of all LiCoO<sub>2</sub> and all LiMn<sub>2</sub>O<sub>4</sub> cathode materials: available literature data and results from this study. Thickness of the material, when reported, is also included. In all the references, aluminum describes the current collector

Material/method	Specific heat (J g <sup>-1</sup> K <sup>-1</sup> )	Thermal diffusivity 10 <sup>-3</sup> (m <sup>2</sup> s <sup>-1</sup> )	Density × 10 <sup>3</sup> (g m <sup>-3</sup> )	Thermal conductivity 10 <sup>3</sup> (W m <sup>-1</sup> K <sup>-1</sup> )	Thickness × 10 <sup>3</sup> (m)	Ref.
(a)						
Cathode (wet)manufacturer	1.1738	0.6021 <sup>a</sup>	2.6175	1.85	109.224	29
Cathode (wet)estimated	0.849	0.541 <sup>a</sup>	2.81	1.29	—	30
Cathode (wet)measured	1.2692	0.5346 <sup>a</sup>	2.3285	1.58	—	31
Cathode (dry)estimated	—	1.23	3.135	2.33	185	33
Composite (wet)estimated	1.134	0.658 <sup>a</sup>	2.92	2.18	190	32
LiCoO <sub>2</sub> thin film/measured	0.73	0.846 <sup>a</sup>	2.5	1.48	92	38
LiCoO <sub>2</sub> thin film/estimated	0.77	0.846 <sup>a</sup>	2.5	1.48	92	37
Electrolyte (LiPF <sub>6</sub> /EC + DMC + DEC) —	0.1338	2.6	1.29	0.45	—	37
Aluminum/measured	0.897	97.2	2.7	237	—	19 and 25
Cathode (dry)measured	0.83 ± 0.02	0.23 ± 0.02	2.34 ± 0.03	0.78 ± 0.06 <sup>a</sup>	110	This study
Composite (dry)estimated	0.74 ± 0.02	0.39 ± 0.02	2.29 ± 0.02	0.66 ± 0.05 <sup>a</sup>	95	This study
(b)						
Cathode (probably dry) + Al/estimated	0.713	4.108 <sup>a</sup>	2.81	8.23	200	34 and 35
Composite (probably dry)estimated	0.7	1.3 <sup>a</sup>	2.5	2.1	80	46 and 47
Composite (dry)estimated	0.77	4.8 <sup>a</sup>	1.12	5	180	40–45
Composite (probably dry)estimated	1.321	0.473 <sup>a</sup>	2.37	1.48	180	48
Composite (probably dry)estimated	1.043	1.034 <sup>a</sup>	2.317	2.5	183	49
LiCoO <sub>2</sub> (dry)estimated	—	90	—	—	—	39
Cathode (dry)measured	0.83 ± 0.02	0.23 ± 0.01	1.73 ± 0.02	0.32 ± 0.02 <sup>a</sup>	160	This study
Composite (dry)estimated	0.81 ± 0.02	0.22 ± 0.02	1.63 ± 0.02	0.29 ± 0.02 <sup>a</sup>	145	This study

<sup>a</sup>—“not specified”. Calculated using relation (3), with  $\rho(T) = \rho_0(1 + \alpha(T))$ , where  $\alpha(T)$ ,  $c_p(T)$  and  $\rho_0(T)$  were taken from the respective reference data.



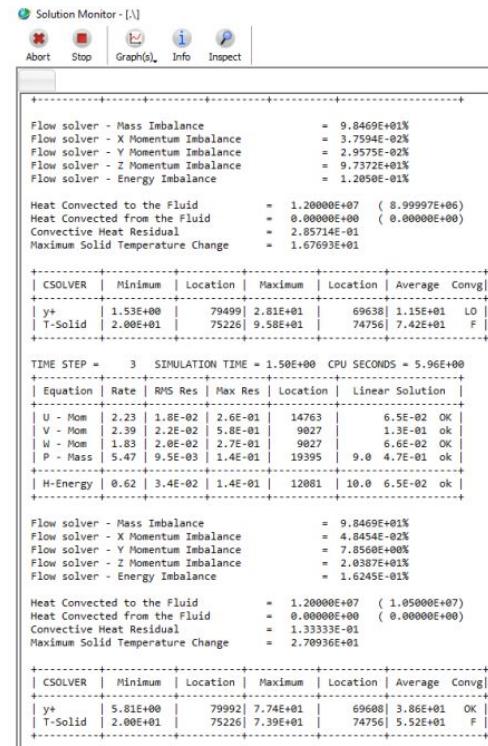
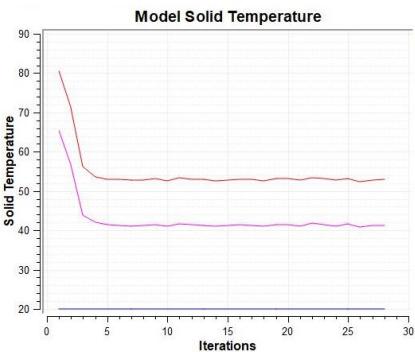
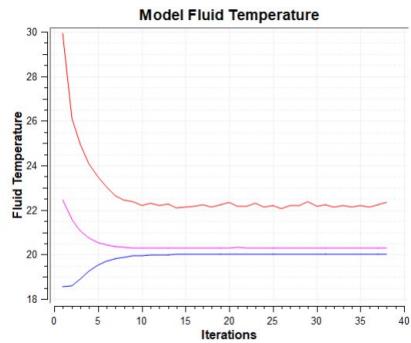
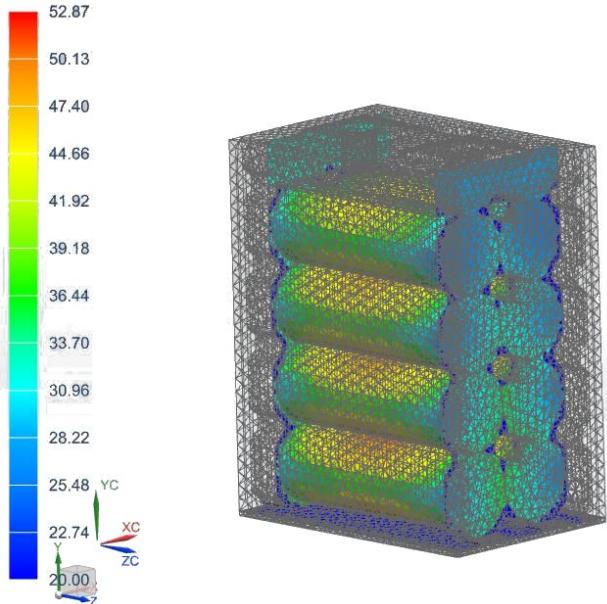
$$\Delta P = \rho \frac{\mu \cdot l \cdot v^2}{2d} = 1,2 \frac{0.38 \cdot 0.45 \cdot 1.42^2}{2 \cdot 0.006} = 28,7 \text{ Pa}$$

Battery material

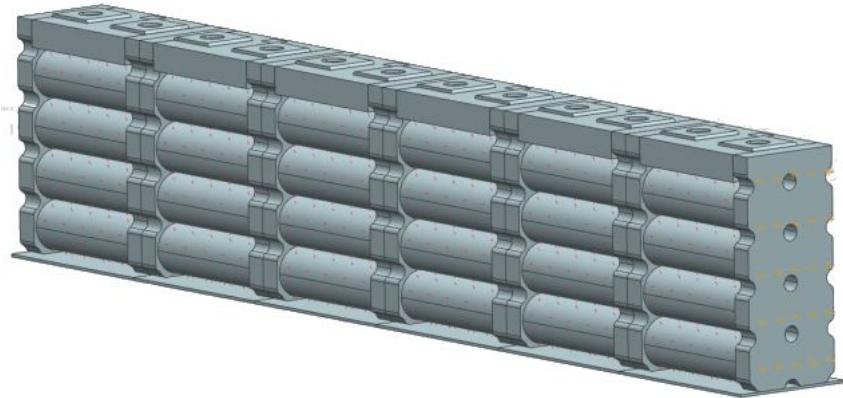
Pressure drops

# Battery CFD Analysis

batteryCellCFD1\_sim5 : Thermal\_solution\_cell Результат  
 Случай нагружения 1, Статический шаг 1  
 Распределение температур - По элементам, Скаляр  
 Мин. : 20.00, Макс. : 52.87, Единицы = °C

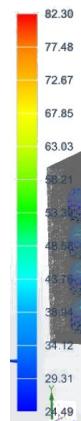


# Battery CFD Analysis

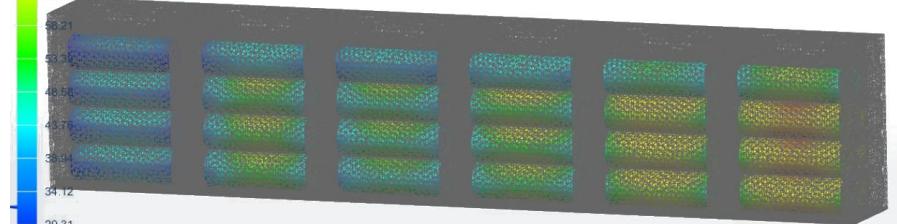


We have 4 battery cell in length

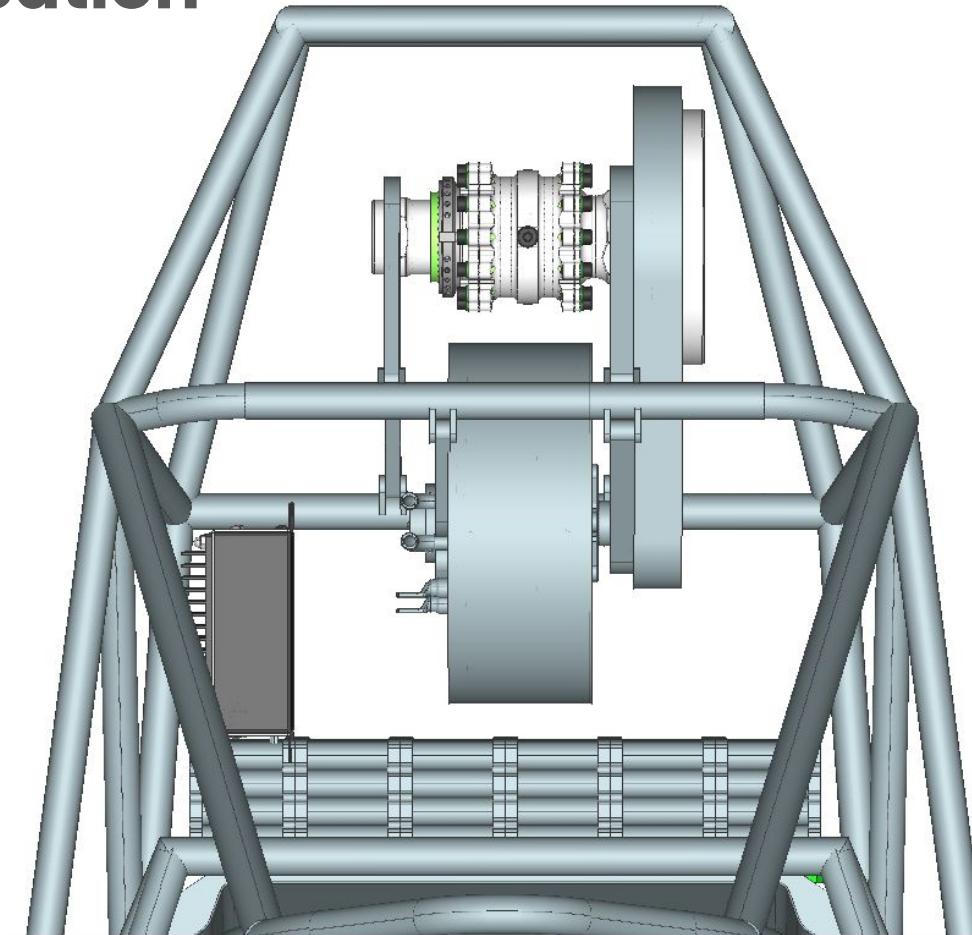
CFD\_sim2 : Segment Результат  
Случай нагружения 1, Статический шаг 1  
Распределение температур - По узлам, Скаляр  
Мин. : 24.49, Макс. : 82.30, Единицы = °C



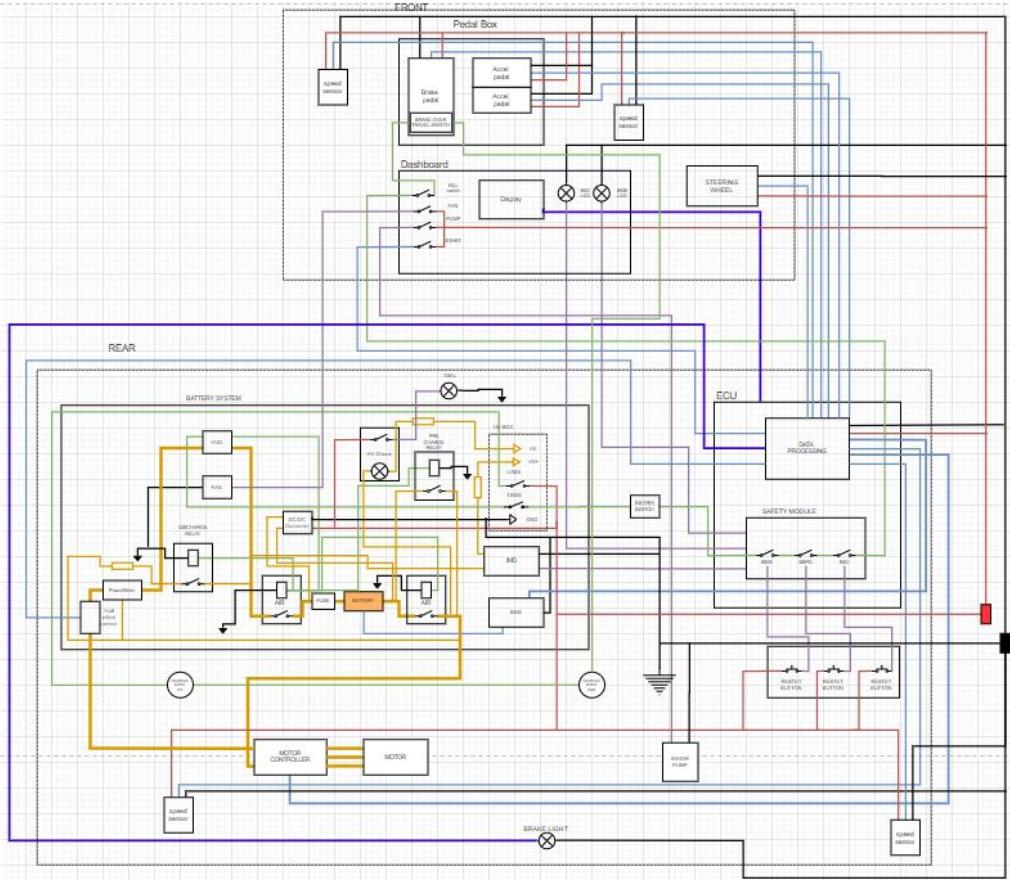
The most loaded area



# Battery location



# Wiring

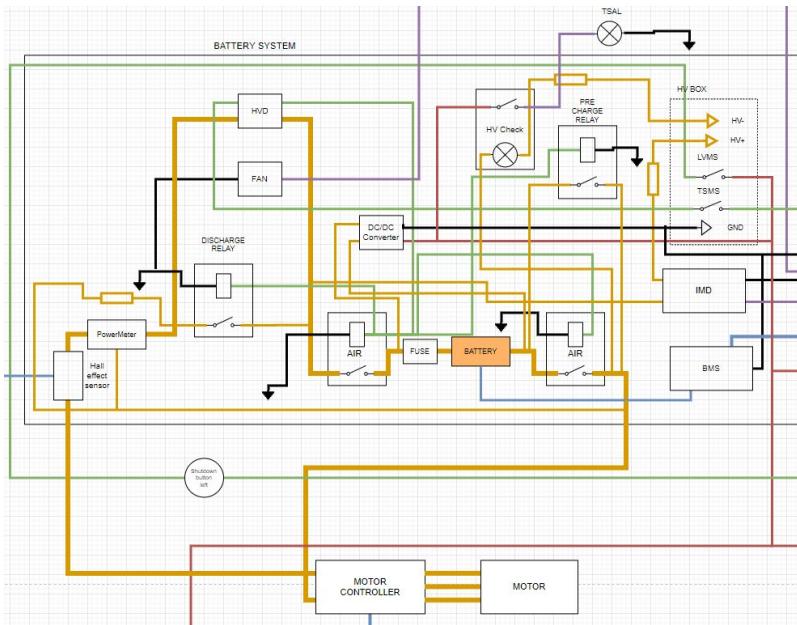


Full car wiring:

- Low voltage circuits
- High voltage circuits
- Safety circuits
- Logic inputs/outputs

All of the components are thought through and selected

# Full powertrain



Orion BMS 2  
Cell balancing  
Cell monitoring



Emrax 228  
109kW motor



Bamocar d3  
motor  
controller

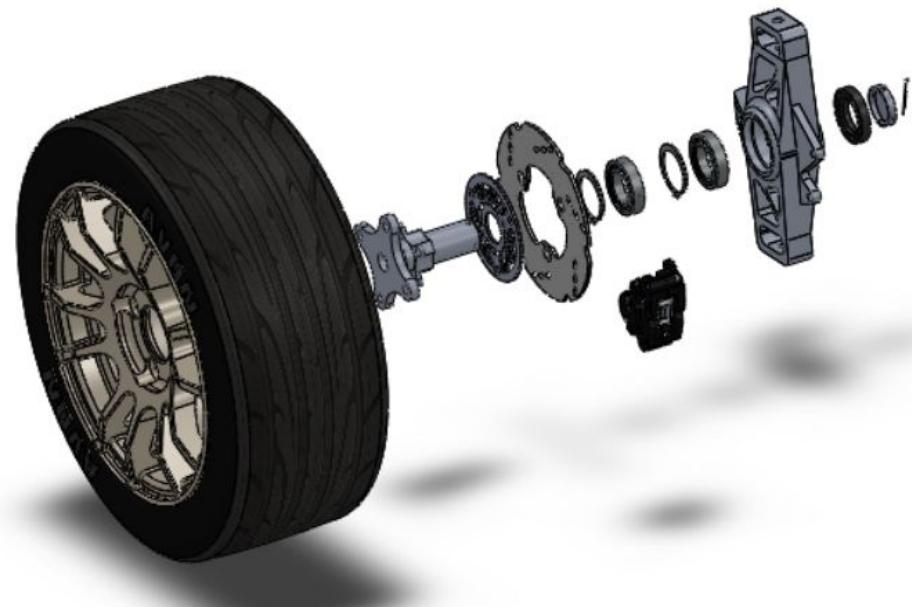


4 segments 24s7p  
Total voltage 344V  
Total capacity 6kWh  
Mass w/o container 34kg

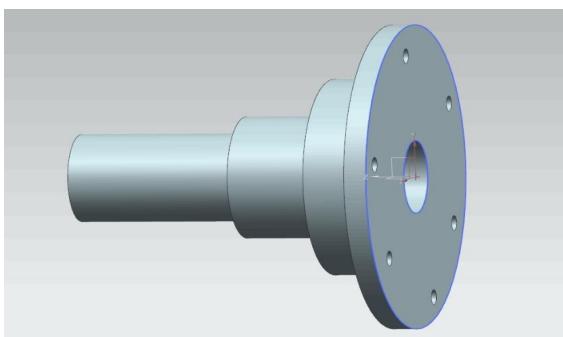
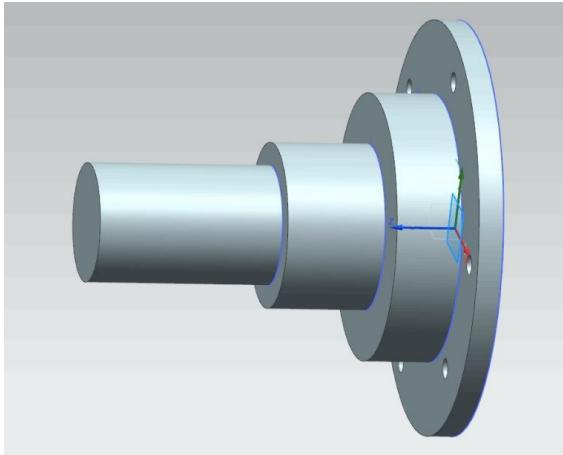
# Mechanism of Up-Right part and Wheelhub system

This whole assembly is linking

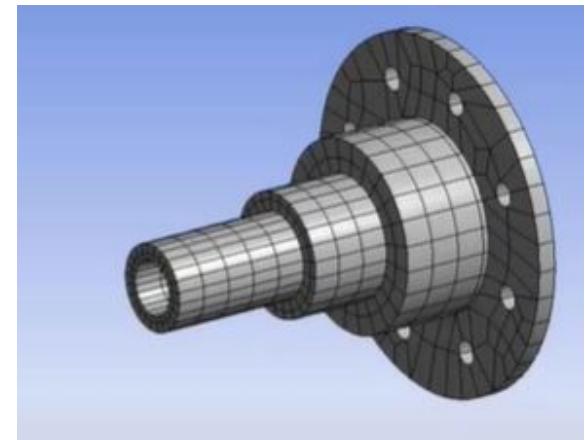
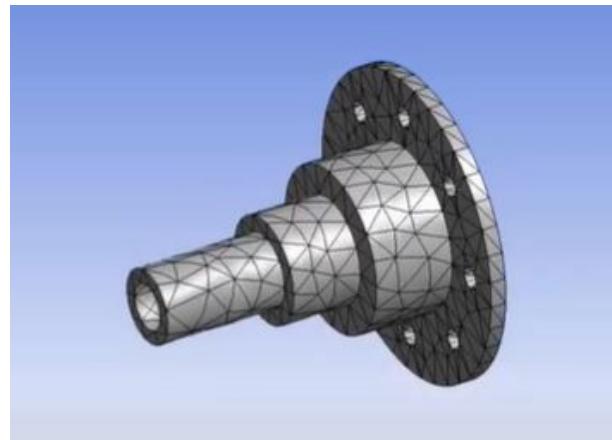
suspension system with front-wheel



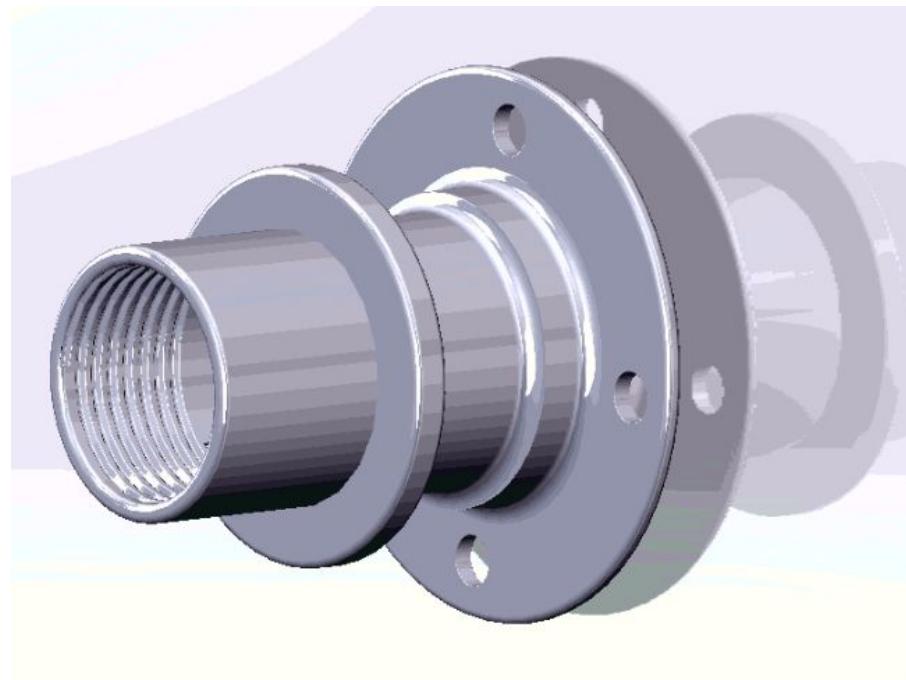
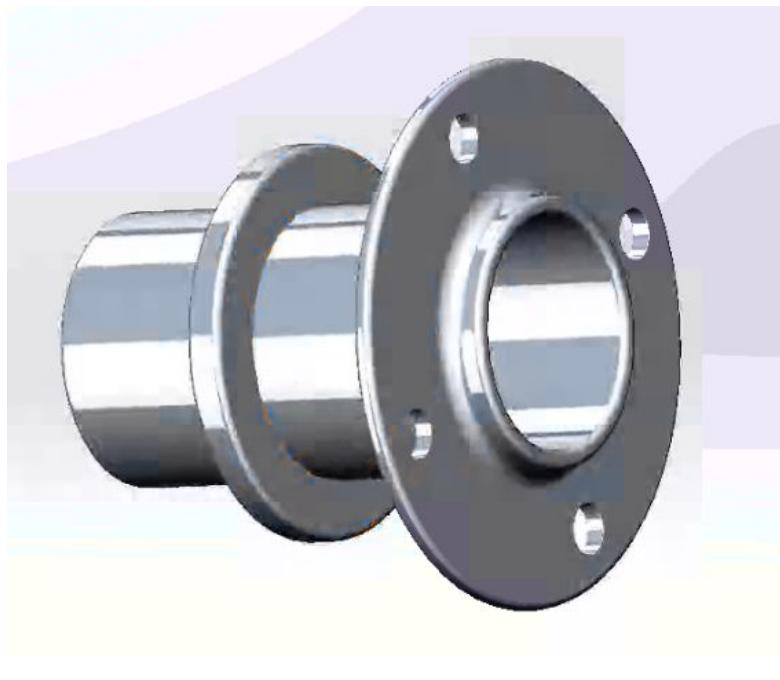
# 3-D model of wheel hub



1. This model has been made in NX software.
2. For simulation, model is kept simple. Thread and external notches are not considered.

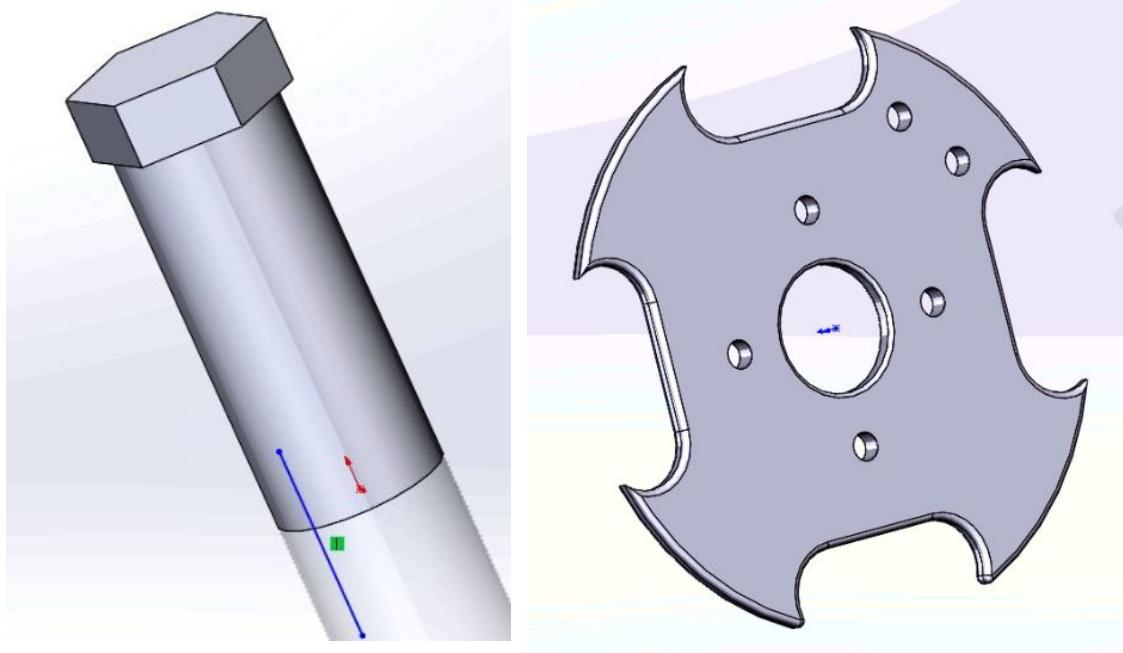


# Final Model of wheelhub system



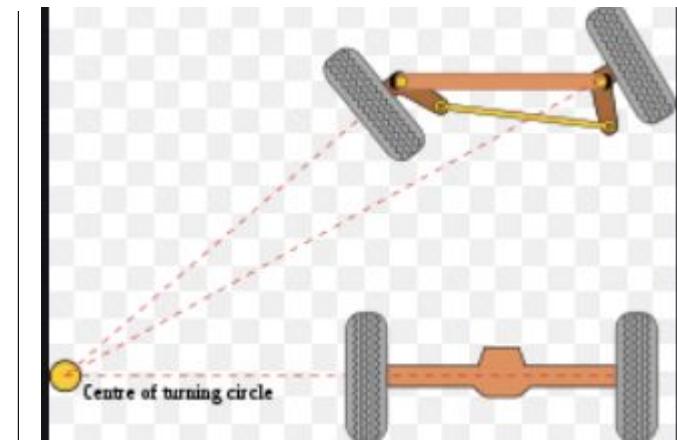
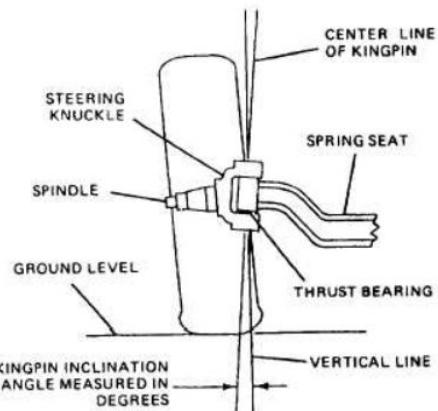
# Disc-brake supporter

Breaking system will  
be attached to the  
plate.

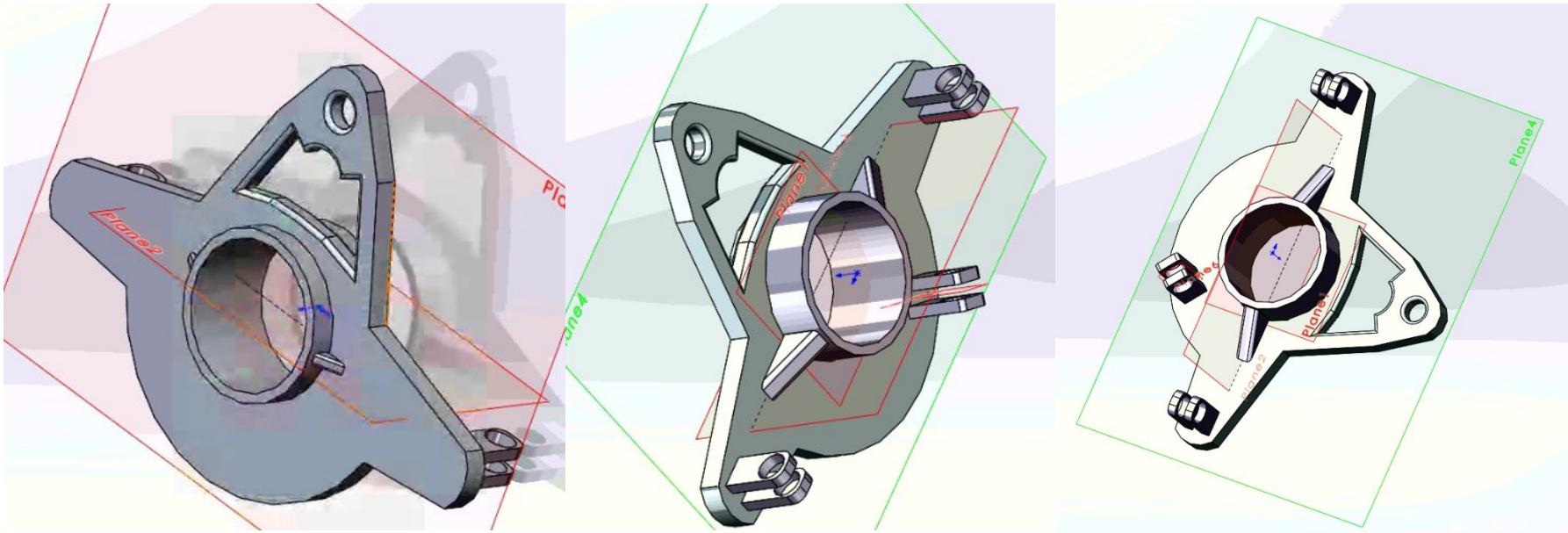


# Calculations require to design Up-Right part

1. Distance between upper and lower mounting point of suspension system.
2. Kingpin angle.
3. Caster angle.

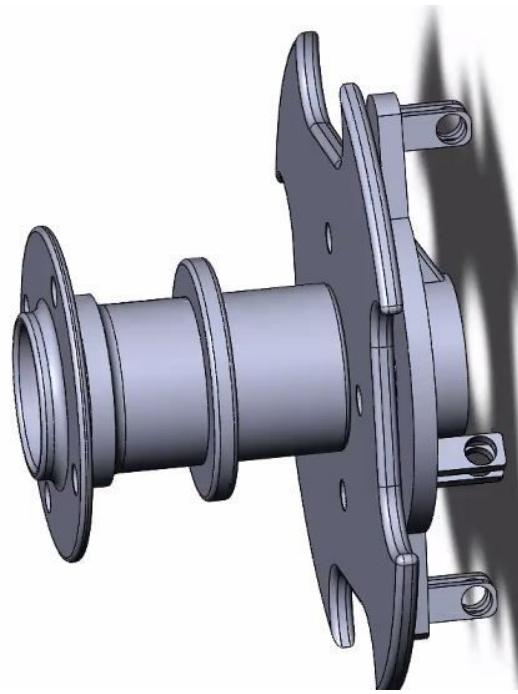
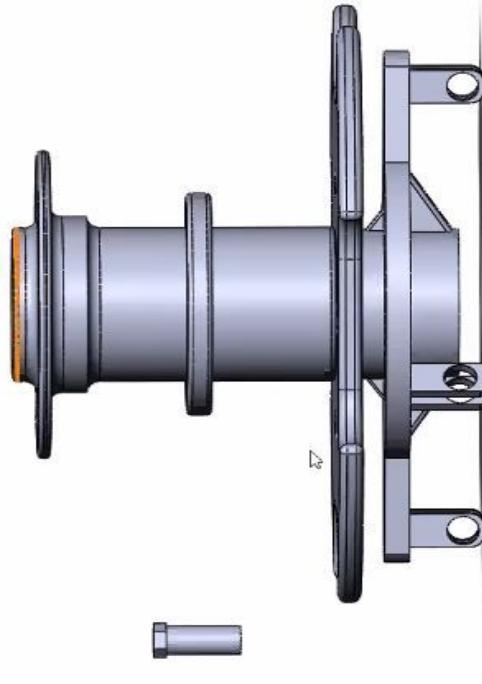


# Up-Right part



# Assembly

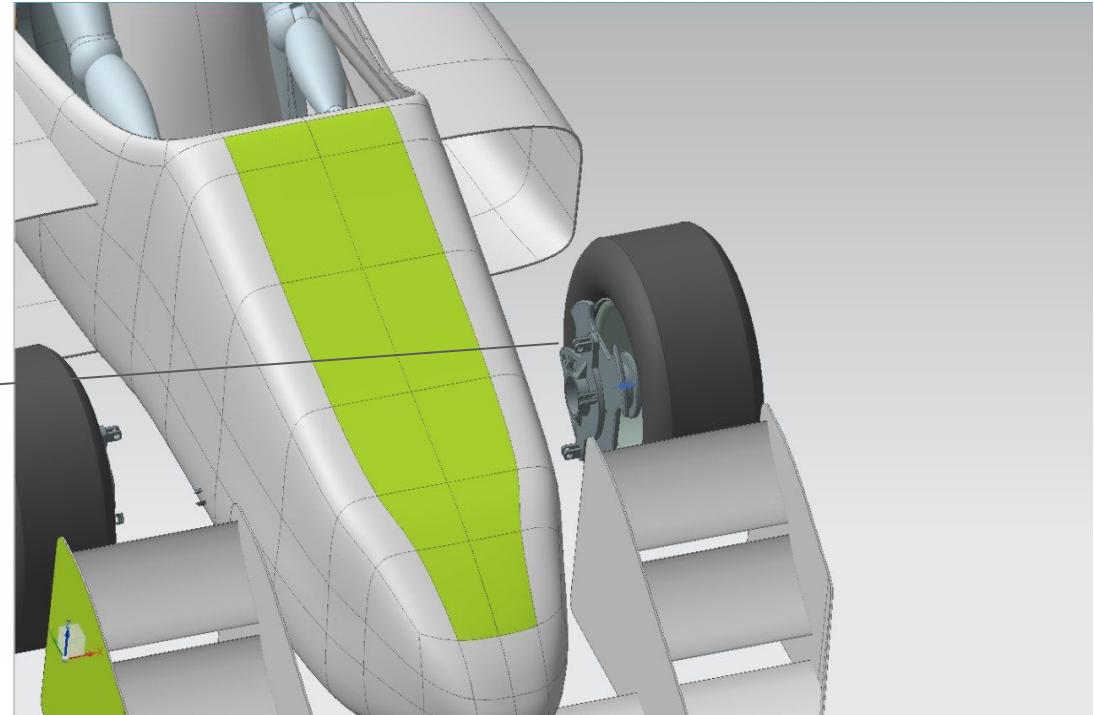
This is how the assembly look like.



# Inserting assembly in car

System has been  
successfully installed

Wheelhub and  
upright assembly

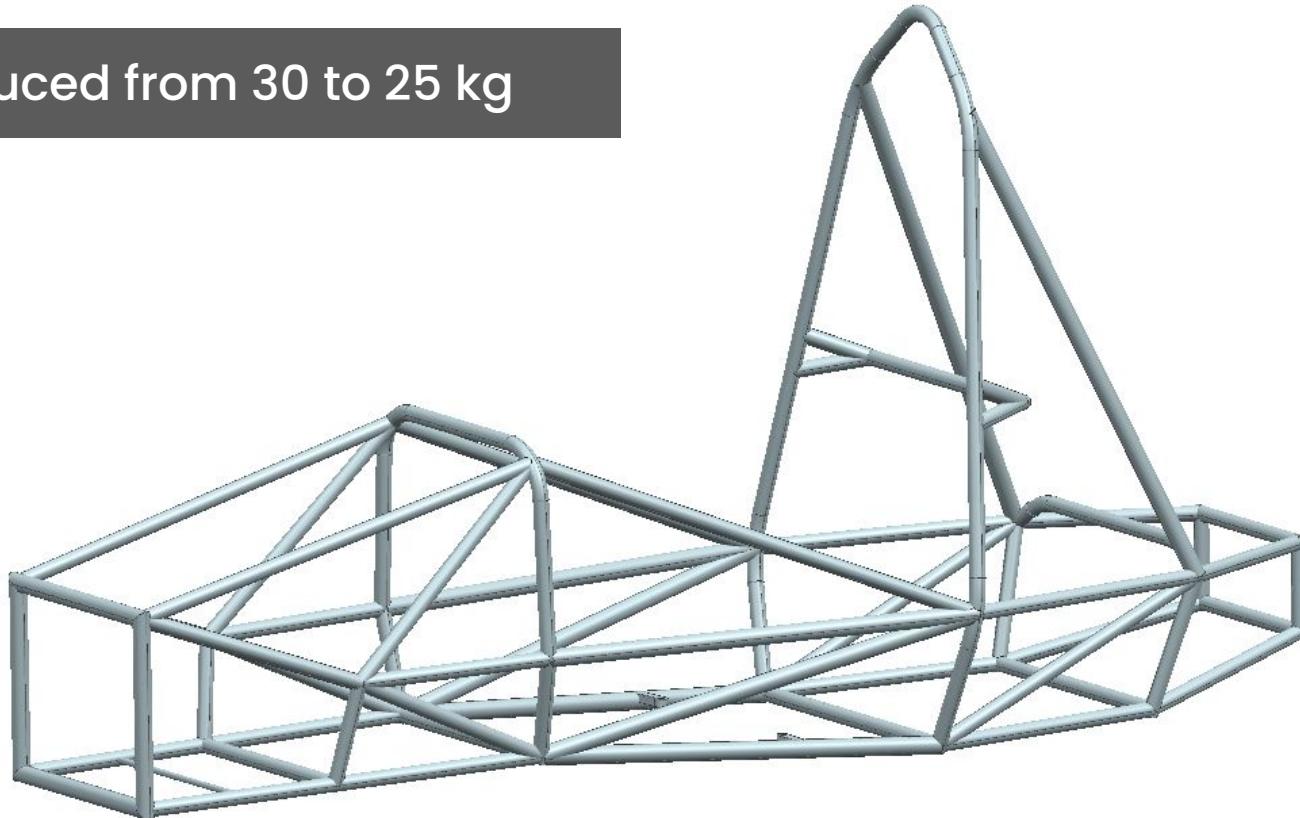


# Strength analysis

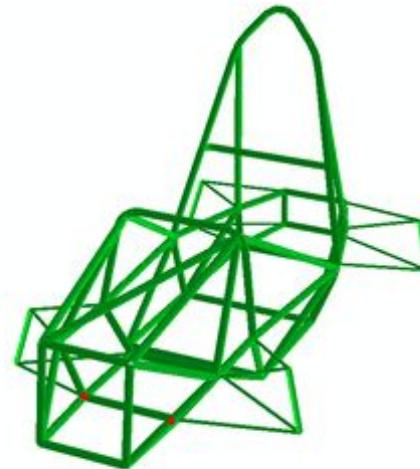
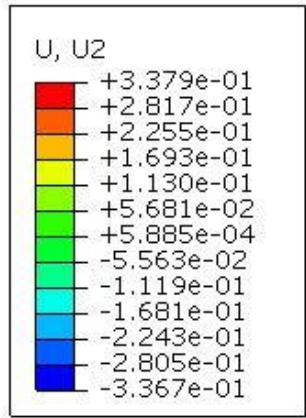


# Frame

Mass reduced from 30 to 25 kg



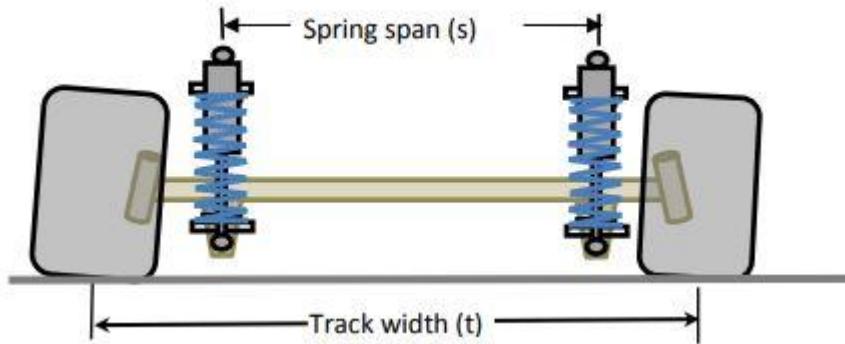
# Torsional stiffness of the frame



Torsional stiffness

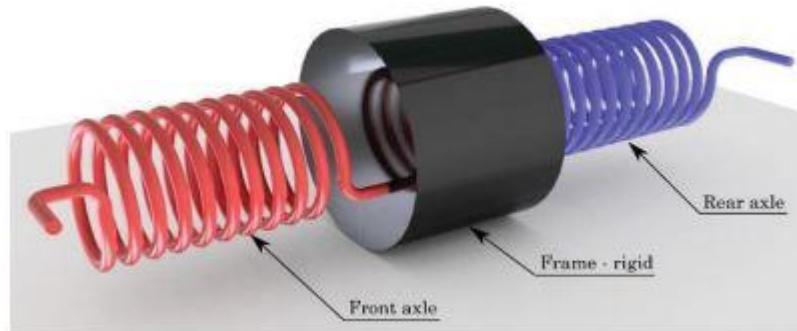
$$C_T = \frac{T}{\theta} \left[ \frac{Nm}{deg} \right] = 940 \left[ \frac{Nm}{deg} \right]$$

# Roll stiffness of suspension



Roll stiffness of each wheel axle

$$C_{axle} = \frac{TS^2 K_{dumper}}{1375} \left[ \frac{Nm}{deg} \right]$$



Overall roll stiffness

$$C_{roll} = \frac{1}{\frac{1}{C_{rear}} + \frac{1}{C_{front}}}$$

# Analysis of results

## Optimal selection of dumper

The required torsional/roll stiffness ratio

$$\frac{C_T}{C_{roll}} \approx 4$$

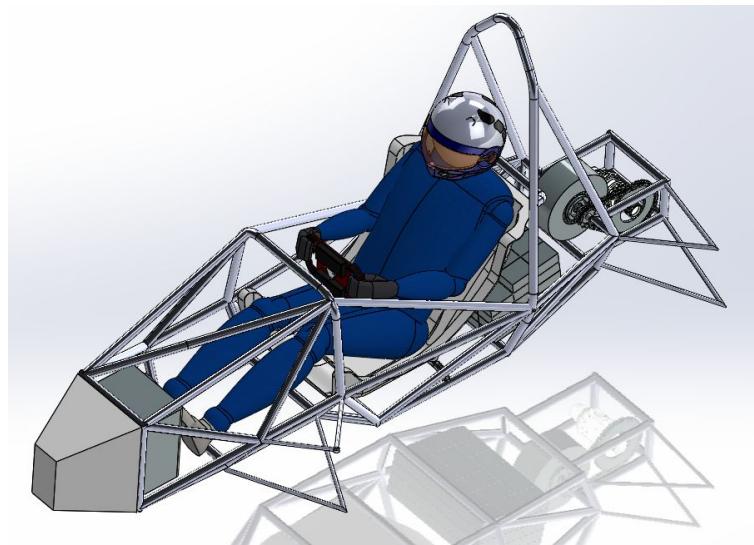
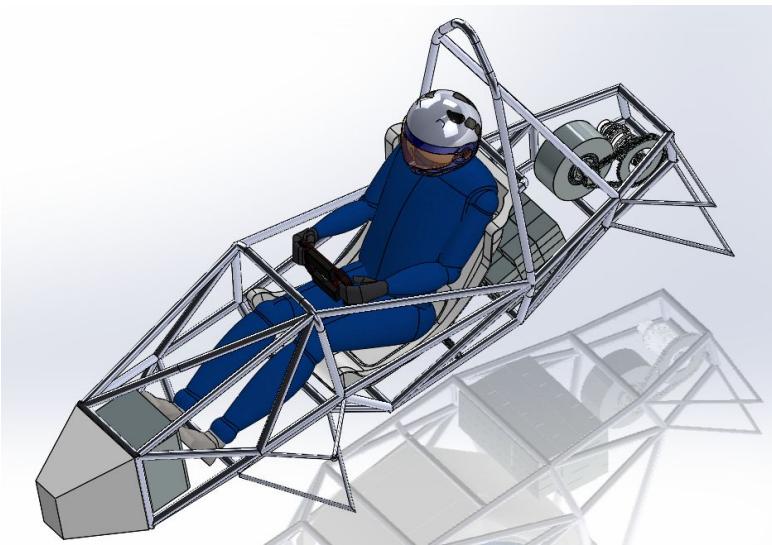
$$C_T = 940 \left[ \frac{Nm}{deg} \right] \rightarrow C_{roll} \approx 235 \left[ \frac{Nm}{deg} \right]$$



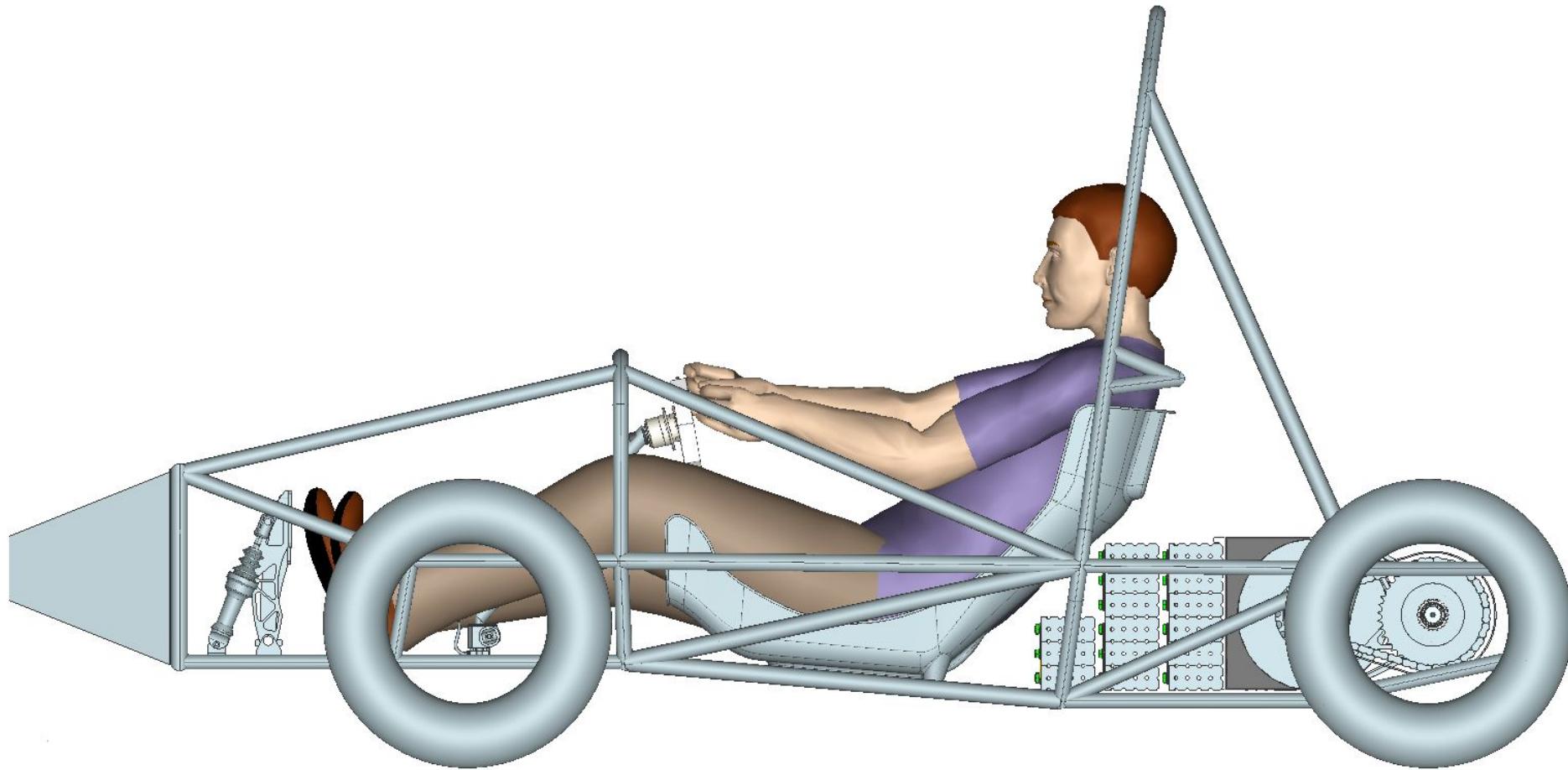
Optimal stiffness of dumpers

$$K_{dumper} = 45 \left[ \frac{N}{m} \right] = 400 \left[ \frac{lb}{in} \right]$$

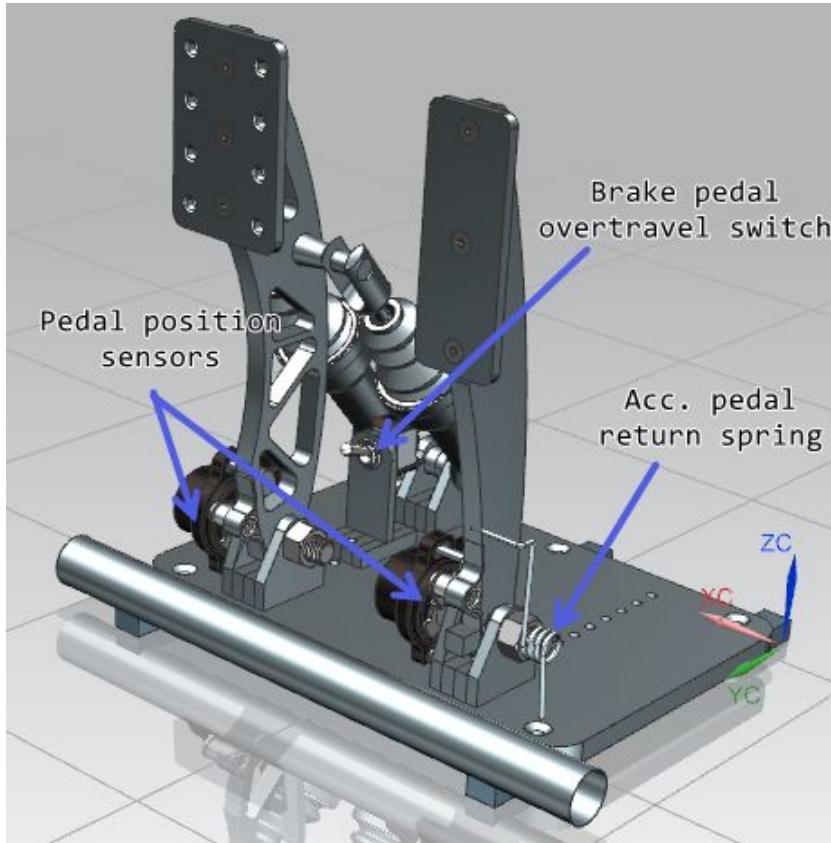
# Iterations 7 and 8



# Pedal assembly & braking system

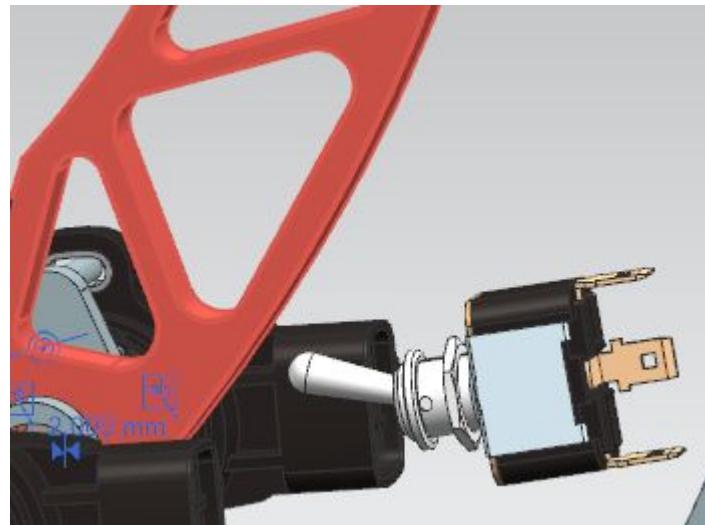


# Pedal assembly & braking system

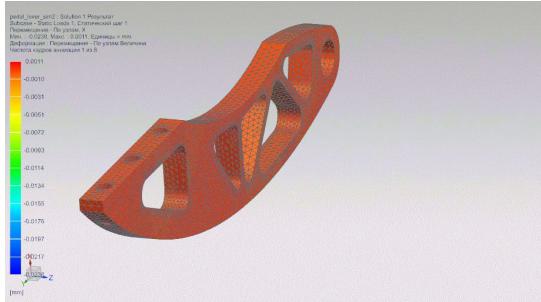
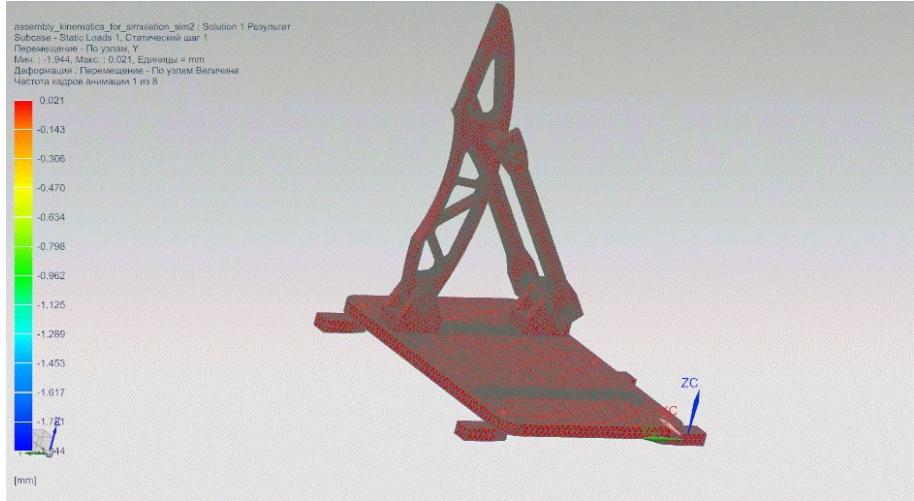


Material: D16T

Welded to the frame

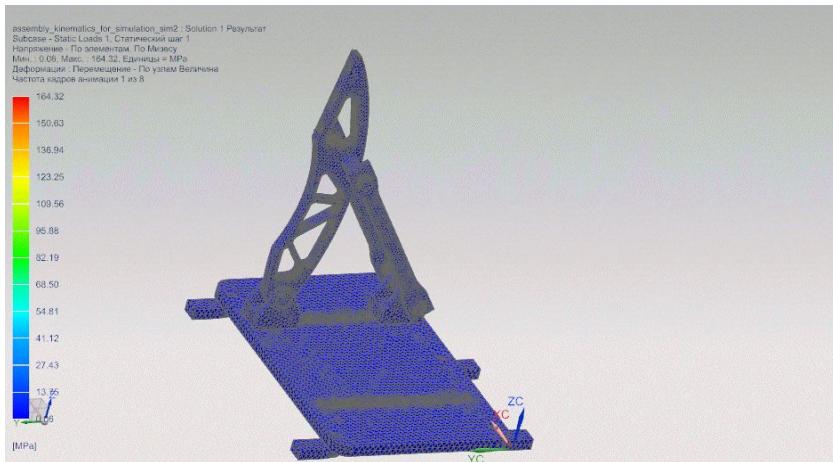


# Pedal assembly & braking system



Simplified model for simulations

FoS = 4



# Verification

**How do we make sure, our car is what it should be?**

**3D model verification**

**Assembly verification**

TRAINING WORKSPACE Formula\_Student

+ Specification + Folder ▾

All requirements

- A\_Administrative\_Regulations
  - A1\_Competition\_Overview
    - A1\_1\_Competition\_Objective
    - A1\_2\_Competition\_Procedure
    - A1\_3\_Competition\_Information
  - A2\_Vehicle\_Eligibility
    - A2\_1\_Student\_Competition
    - A2\_2\_First\_Year\_Vehicles
    - A2\_3\_Base\_Vehicles
  - A3\_Rules\_of\_Conduct
    - A3\_1\_GeneralOfficials\_Authority
    - A3\_2\_Official\_Instructions
    - A3\_3\_Arguments\_withOfficials
    - A3\_4\_Usportsmanlike\_Conduct
    - A3\_5\_Violations\_of\_Intent
    - A3\_6\_Questions\_about\_the\_Rules
    - A3\_7\_Protests
  - A4\_General\_requirements\_for\_Teams&Participants
  - A5\_Documentation&Deadlines
  - A6\_General\_Rules
  - D\_Dynamic\_Events

REQUIREMENTS A1\_2\_Competition\_Procedure

Assigned components Teams

Description Event description

Requirements

IDENTIFIER ↑ TEXT

The competition is split into the following classes:

- Internal Combustion Engine Vehicle (CV)
- Electric Vehicle (EV)
- Driverless Vehicle (DV) (which are either CV or EV)

A1.2.1

A1.2.2

A1.2.3

A1.2.4

A1.2.5

A1.2.6

A1.2.7

T3.17.1-453	Impact_Attenuator	Each vehicle must be equipped with an IA.	Inspec... ▾	Verified ▾	IA present	1/1 N/A
		The IA must be:				
		<ul style="list-style-type: none"><li>Installed forward of the front bulkhead.</li><li>At least 100mm high and 200mm wide for a minimum distance of 200mm forward of the front bulkhead.</li></ul>				
		<ul style="list-style-type: none"><li>Not able to penetrate the front bulkhead in the event of an impact.</li><li>Attached securely and directly to the Anti Intrusion Plate (AIP).</li><li>Not part of the non-structural bodywork.</li><li>Designed with a closed front section.</li><li>Cannot be wider or higher than the AIP.</li></ul>	Review ▾	Verified ▾	+	1/1 N/A
		On all vehicles, a 1.5mm solid steel or 4.0mm solid aluminum AIP must be integrated into the IA.				
		<ul style="list-style-type: none"><li>If the IA and AIP (IA assembly) are bolted to the front bulkhead, it must be the same size as the outside dimensions of the front bulkhead.</li></ul>	Inspec... ▾	Select... ▾	+	0/1 N/A
		<ul style="list-style-type: none"><li>If it is welded to the front bulkhead, it must extend at least to the centerline of the front bulkhead tubing in all directions.</li><li>The AIP must not extend past the outside edges of the front bulkhead.</li></ul>				
		Alternative AIP designs are permissible if equivalency to T3.17.3 is proven by physical testing as in T3.19.2.	Test ▾	Select... ▾	+	0/1 N/A

# Validation



**That's our first race!**

# Price

Car

Travelling

Marketing  
and PR

6.6 million

2 million

0.5 million

# Goals reached



- There's a possibility to host the competition in Skoltech
  - Car development paper presented on the conference
    - Industrial Immersion collaboration with partners
    - Registration for FS Switzerland confirmed!

## Social



Latest news



[@skoltech\\_racing](#)



Communication



[formula.skoltech.ru](#)

## Private



Purchases and contacts



[racing@skoltech.ru](mailto:racing@skoltech.ru)

## Coming

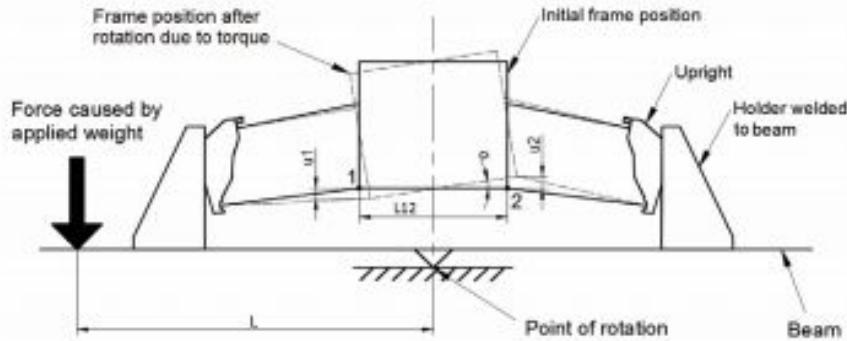




**Thank You!  
Keep Safe!**

# Torsional stiffness of the frame

## Additional

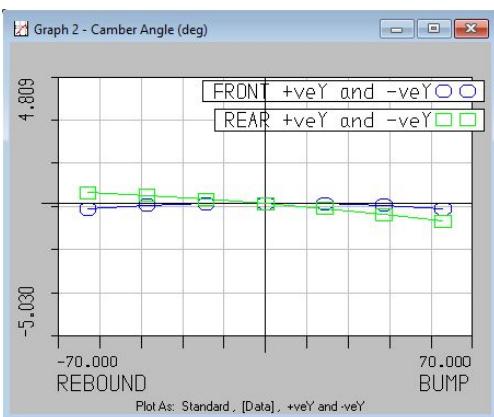
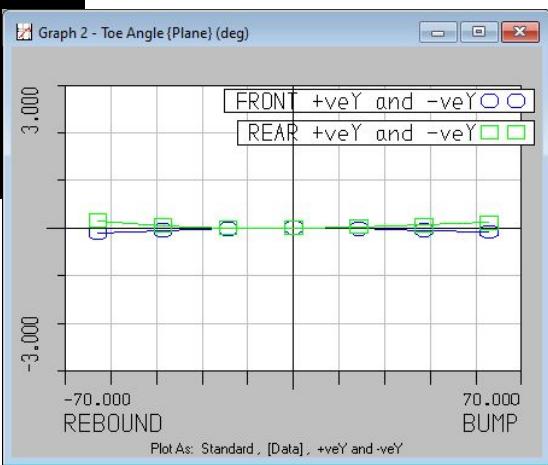
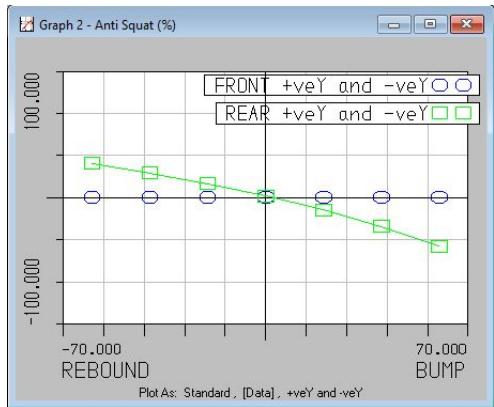
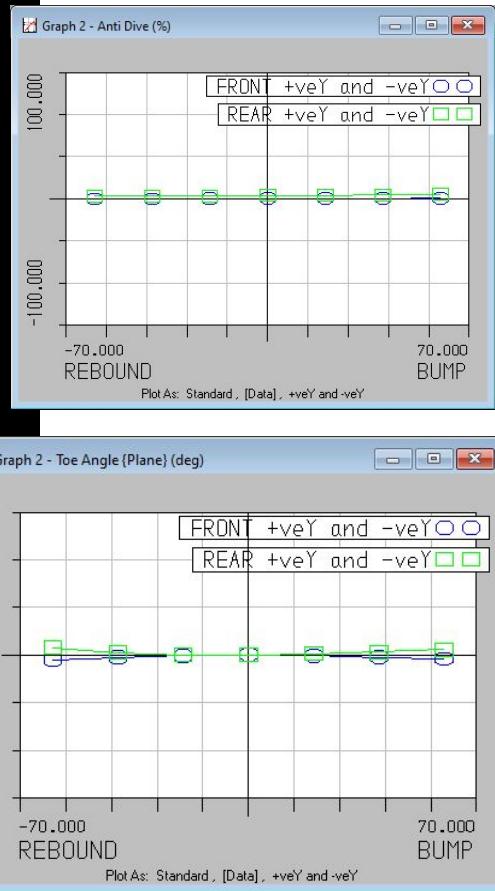
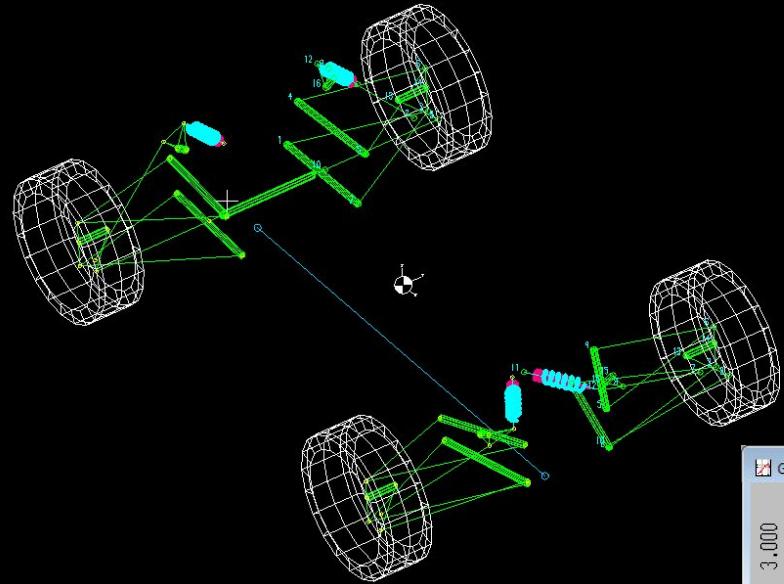


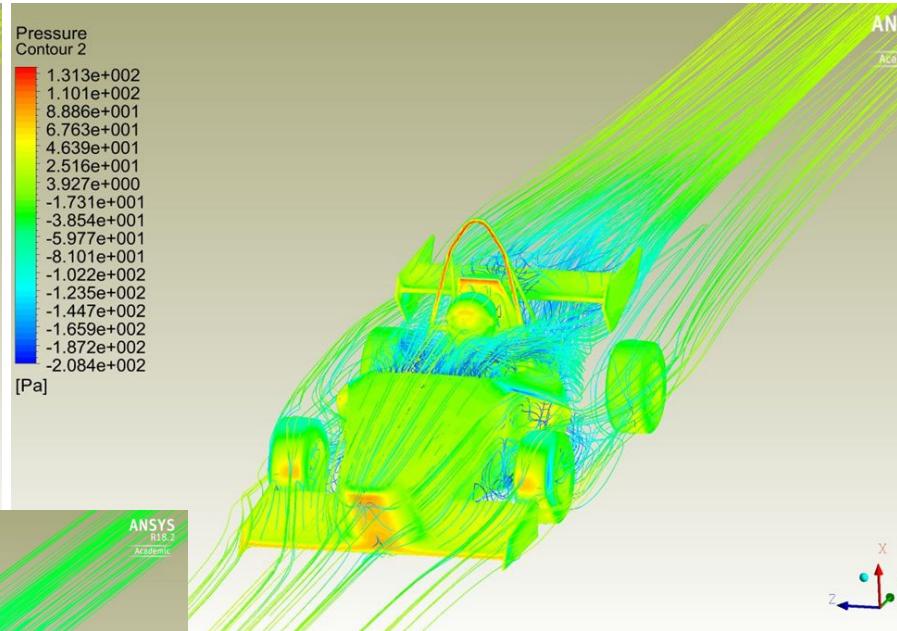
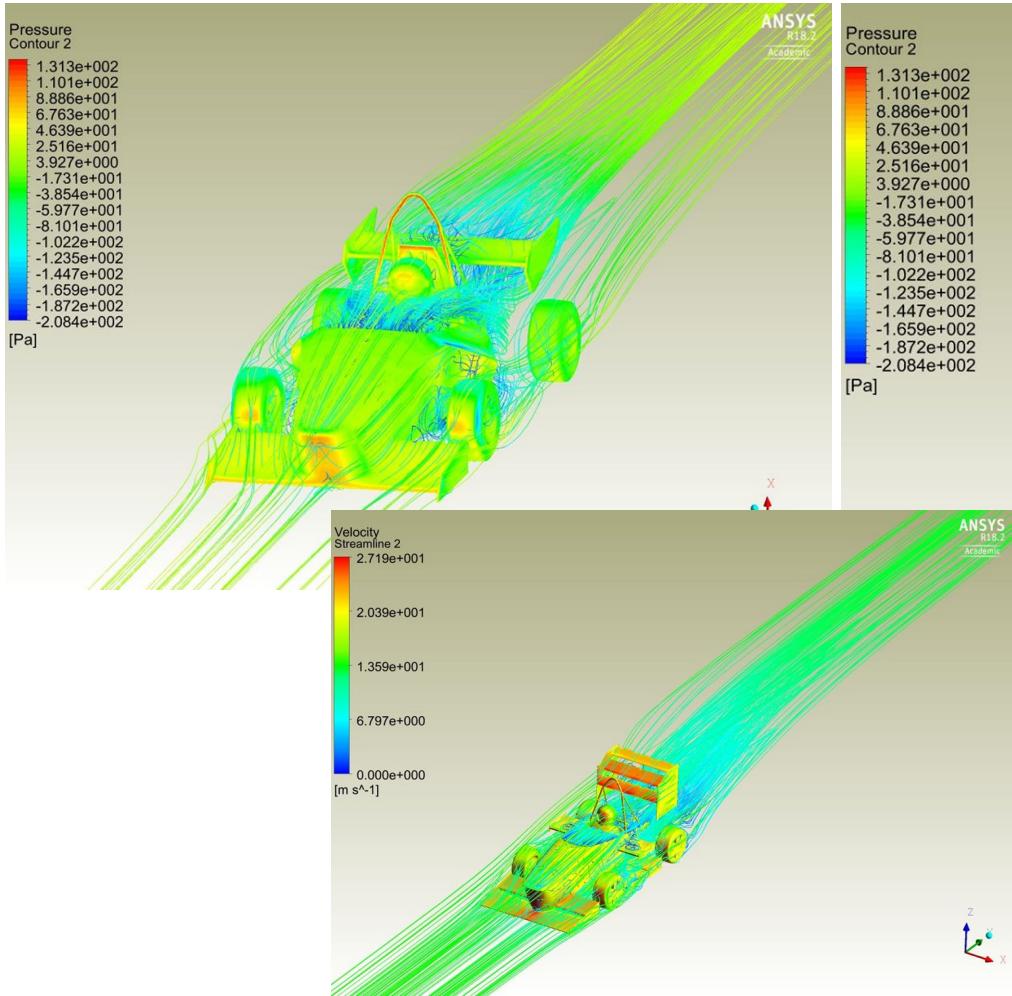
$$\theta = \arctan\left(\frac{\mu_1 + \mu_2}{L_{12}}\right) [deg]$$

Torsional stiffness

$$C_T = \frac{T}{\theta} \left[ \frac{Nm}{deg} \right] = 940 \left[ \frac{Nm}{deg} \right]$$

# **CFD analysis**





# CFD analysis





