Jordan University of science and technology

Faculty of engineering
Mechanical engineering department

Graduation project “2”

Project

Design, simulation, stresses and forces analysis for a chassis, front suspension system and steering system of an off-road buggy car

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Table of contents ***page***

Design, simulation, stresses and force analysis for a chassis, front suspension system, and steering system of an off-road buggy car

Preface.

The most mechanism system used worldwide is the car, so through the past years this field had many upgrades and innovations in the concepts of designing the cars, due to the high competition between the manufacturing companies around the world in a race to win the customer satisfaction. The results is a very high technologic cars that covers every aspect in the designing of cars including car performance, safety, luxury, economical aspects, liability and reliability.

Until this moment the Arabic world with all the human and natural resources it has didn't have a footstep in the field of manufacturing and producing cars, with taking in consideration the necessity of cars for the Arabic citizen nowadays and the economical load above these countries for importing the cars, and on the other hand, the high economical benefits from having a local manufactured car, and the saving of the country incomes from being transferred to the foreign countries, which will be reflected on the living level of the country's citizens, for all what is mentioned above, I think that the Arabic countries should have a second thought about the idea of making a local manufactured car.

So for me as a graduated mechanical engineer, and because of my believe that the science only useful when someone could make from it a useful output to life, I choused my graduation project to be a starting point in the way of designing a local car, which is suitable for the country we live in, and could be manufactured using local resources and manufacturing capabilities, so to obtain an economical price car suitable for the average income person.

Car concept.

The basic concept for the car is to be an *off-road one-seated car*, with a rear engine. The car should be suitable for roaming in the Jordanian deserts as in (Wadi rum desert).

Principles adopted in the car.

Some of the principles that I would adopt in this car are: -

1- **To be low in weight as possible.**
2- **A small car in dimensions.**
3- **To use in it local produced mechanical parts as possible.**
4- **To have an energetic look of an off-road sport car.**
5- **Low price car.**
6- **To consist of easy changeable mechanical parts when they are damaged.**
7- **An acceptable level of safety.**

Overview of the car.

The car would have a chassis consist from hollow roll bars, and hollow rectangular sections beams. This will insure a low weight chassis, a low price chassis, which could be made in the university workstations, by just welding the beams to the prescribed dimensions of the chassis. The chassis design and the dimensions of the hollow cross-sections that would be used in it depended on a one-dimensional finite element analysis (FEA) for the chassis using [COSMOSM software].
The body of the car will be the same chassis.

The car will have a motorcycle engine, which will be installed behind the driver seat, at the rear end of the car, in the place that is shown in figure (1).

The figure* below gives an overview for the car and illustration for some points concerning the chassis.

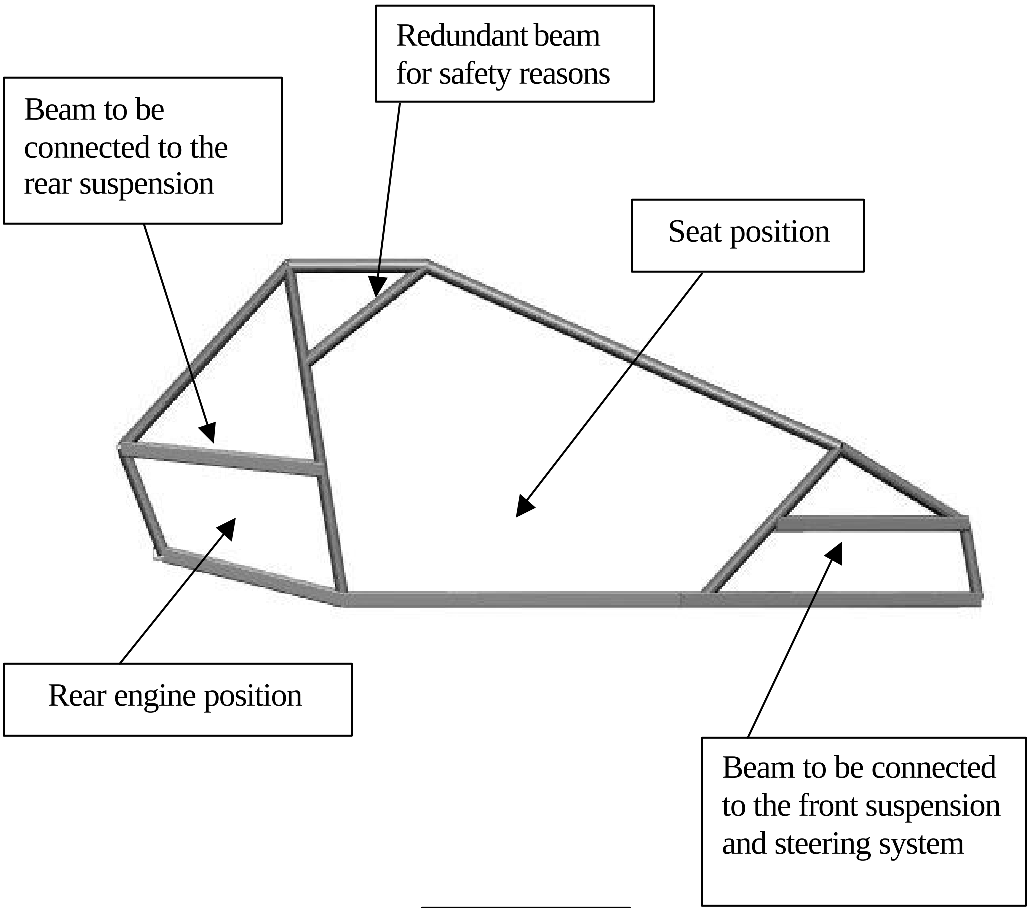


Figure (1)

- **Note: figure (1) is not to scale.**

Chassis design.

After studying some of the chassis shapes of some off-road buggy cars from there pictures which I downloaded from the Internet, and after I could measure the dimensions of a buggy car chassis that I found in (Wadi Al-saiyr industrial city), I started drawing sketches for the chassis depending on the principles I mentioned it before.

Then I used mechanical desktop software, which helps me a lot in visualizing my imagination about the chassis in a 3D solid modeling.

The first modeling of the chassis is shown in figure (2). As it could be seen clearly the curves of the beams is very hard to be manufactured here, as there is not any bending machine that can do such job in the university workstations. The chassis in this model consist totally of hollow roll bars section beams, which is not the best suitable beams to be used incase of bending stresses as the case of lower frame of the chassis, and also the cross section diameter of (10 cm) outer diameter and (8.85 cm) inner diameter in this model is thicker than what should be for a low weight car, the (FEA) results which is included next, prove also that the cross-section should be narrower.

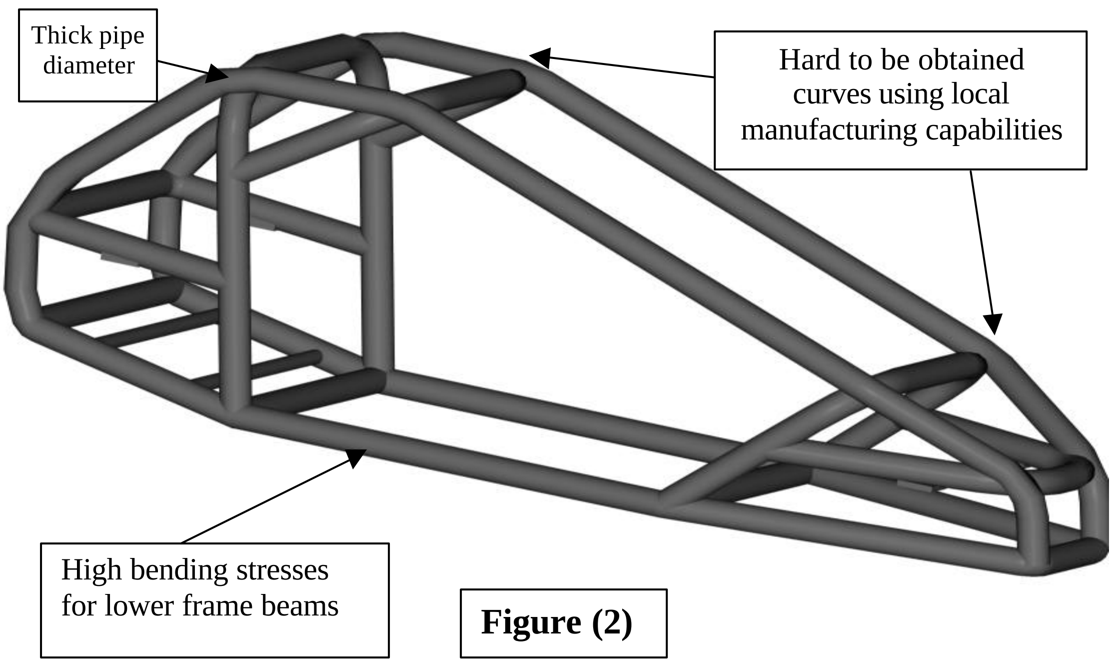
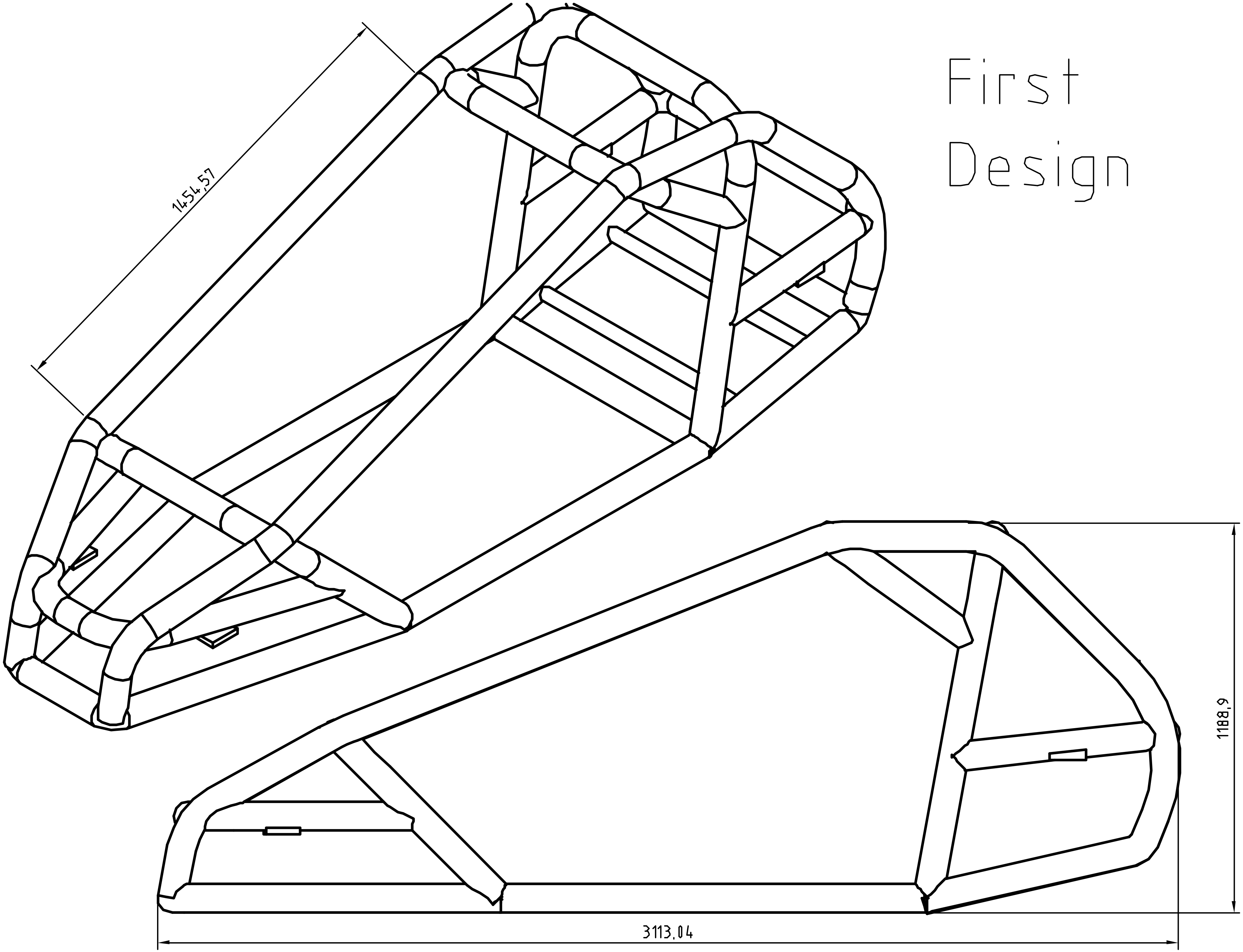


Figure (2)

First Design



Redesign of the chassis.

In the new chassis design, the roll bars of the lower frame and the bars which is connected to the front and rear suspensions changed into hollow rectangular cross-section beams. As seen in the figure all the curves have been removed from the beams in the chassis, so the chassis now consist just of straight beams, which don't any machining operations else to be cut to size using available steel saw then welded together using a DC-welding machine. The mass of this chassis according to Cosmosm and mechanical desktop software is approximately (100 kg) with the cross-section dimensions given in the next figures

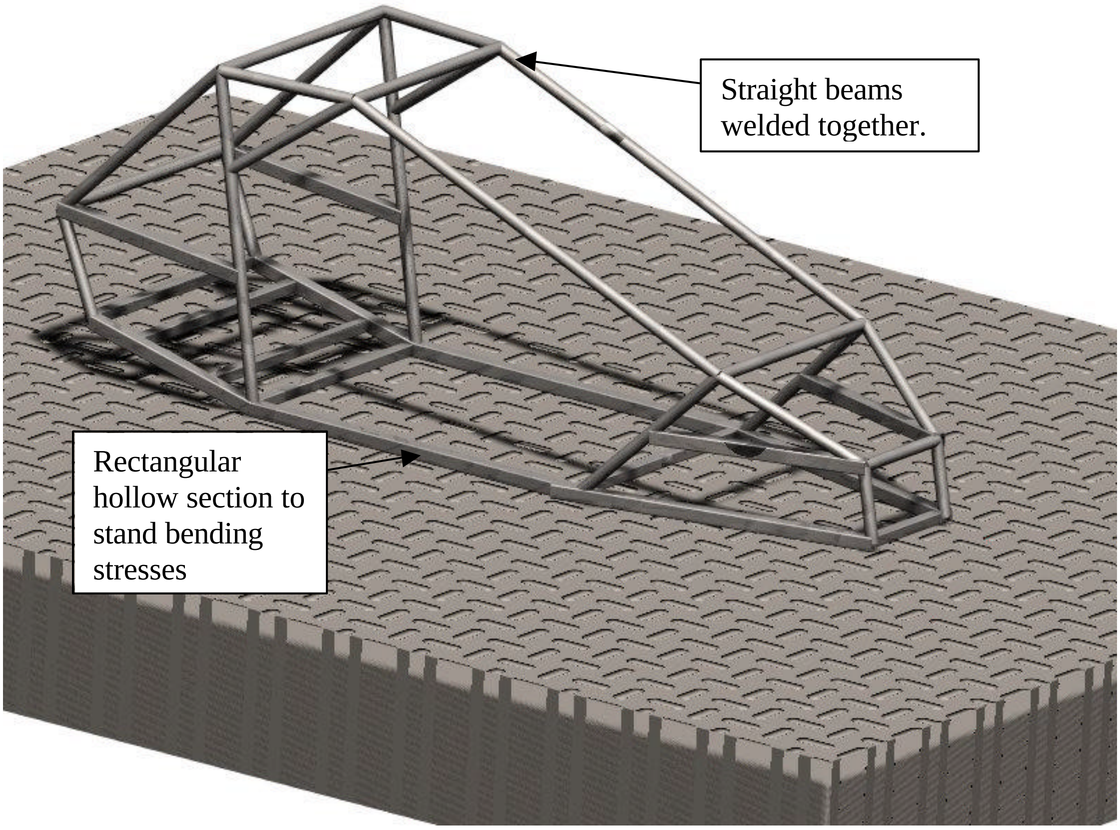
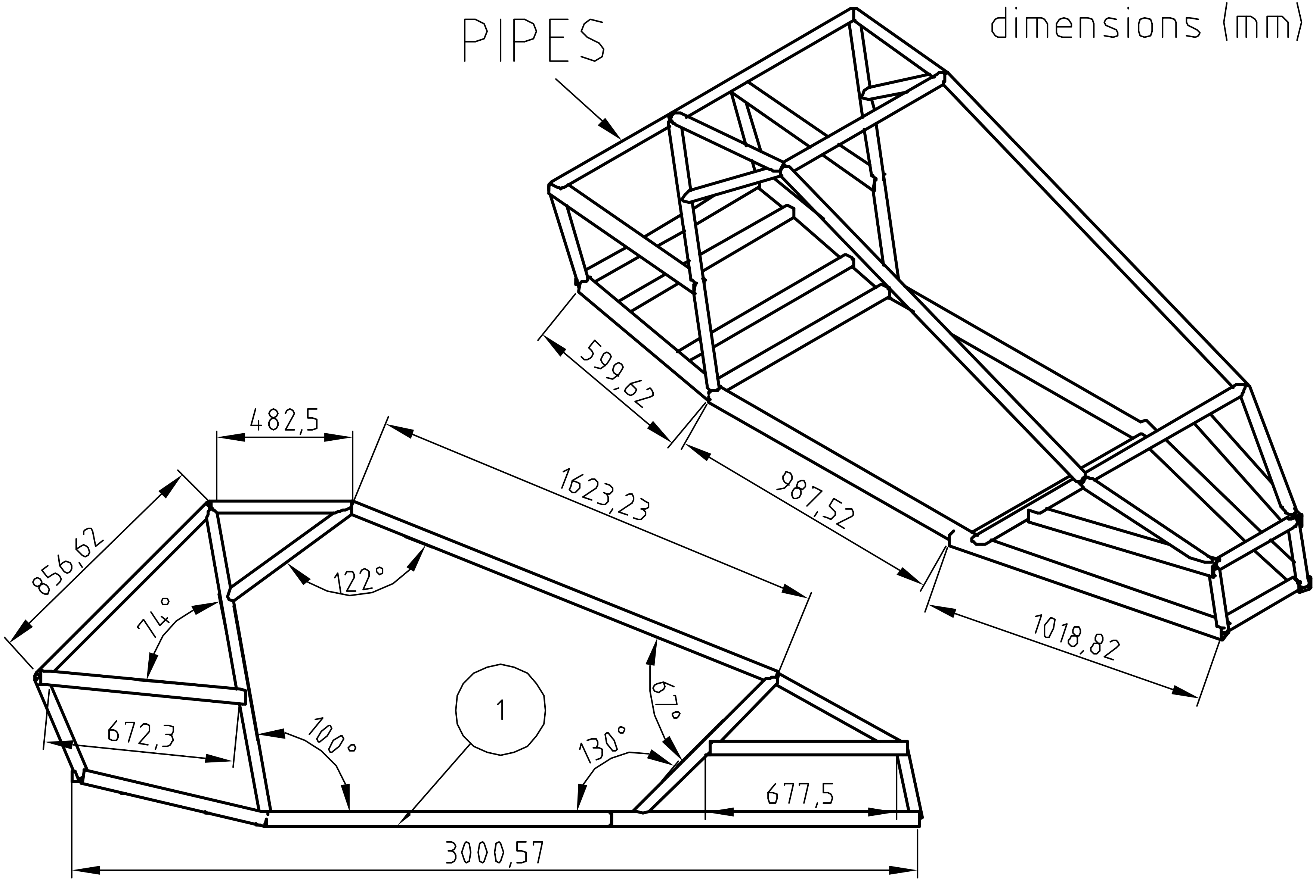


Figure (3)

Item	Qty	Description	Standard
1	16	Hot finished hollow section	ISO 657/14 - 50x50x3.2
2	15	Pipe	ISO 4200 - 42.4x3.6-3

second design of the chassis (projections)
scale $\left(\frac{1}{20}\right)$
dimensions (mm)

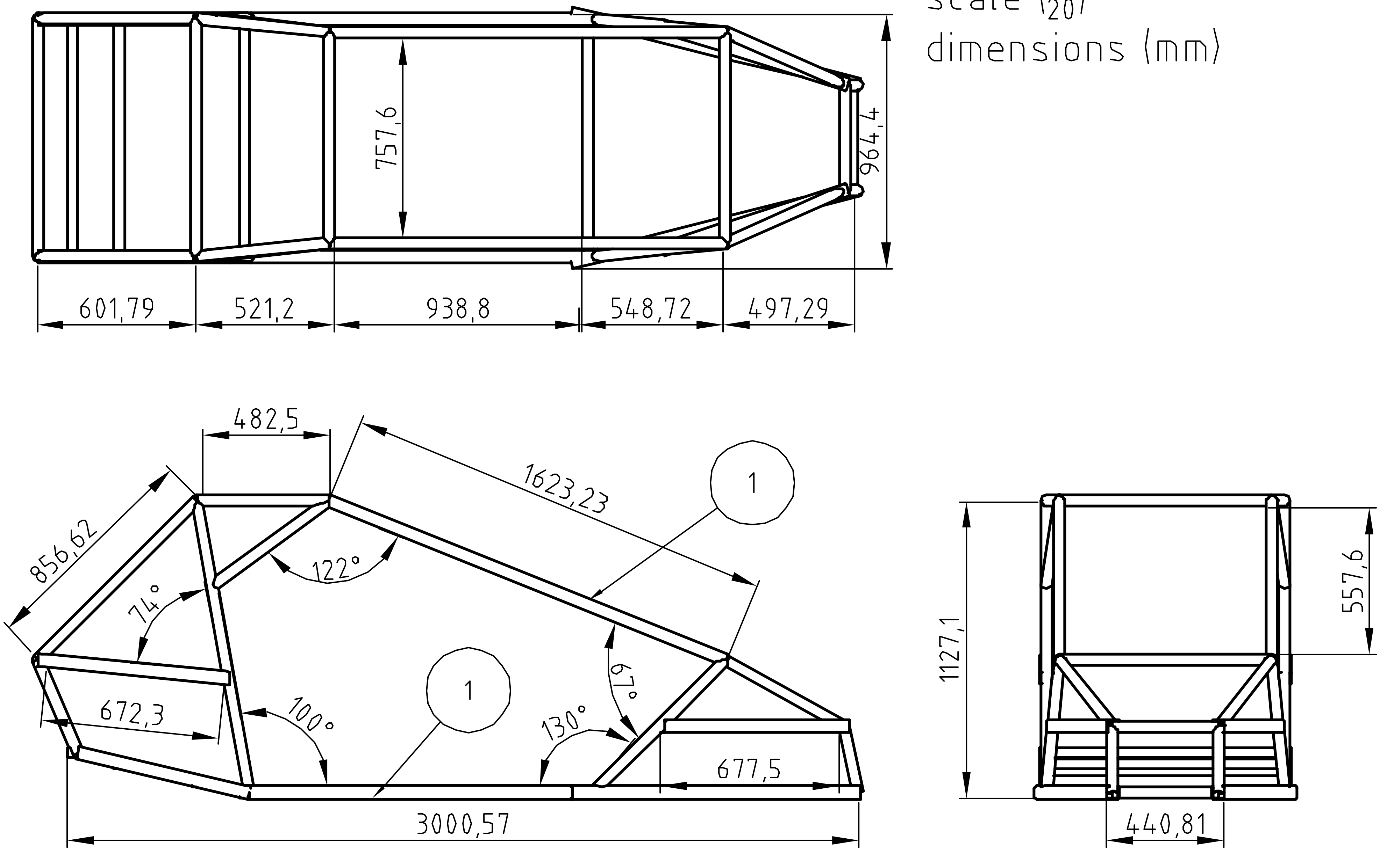


Item	Qty	Description	Standard
1	16	Hot finished hollow section	ISO 657/14 - 50x50x3.2
2	15	Pipe	ISO 4200 - 42.4x3.6-3

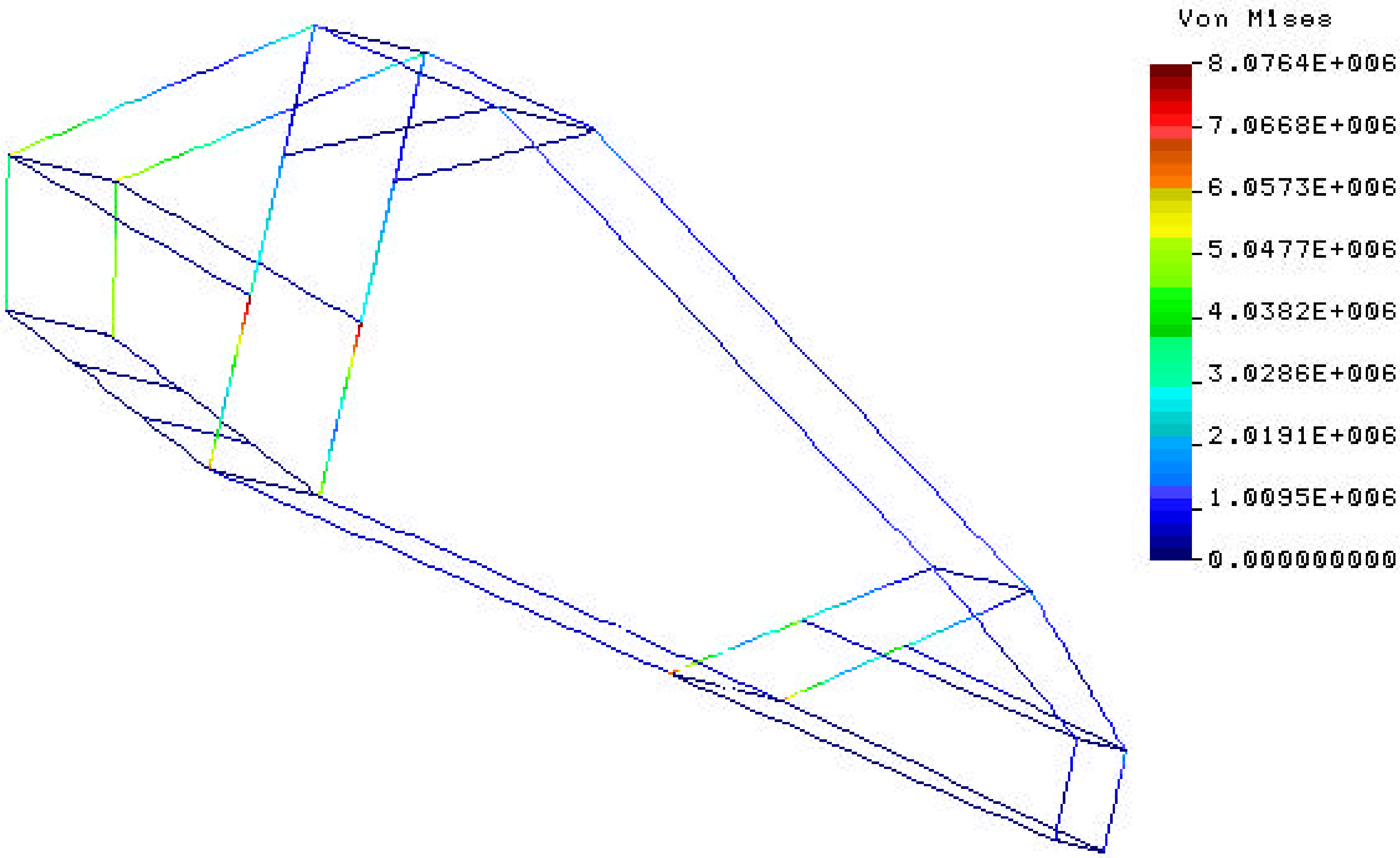
second design of the chassis (projections)

scale $\left(\frac{1}{20}\right)$

dimensions (mm)



VWUHVV[EEPS



Von Mises
8.0764E+006
7.0668E+006
6.0573E+006
5.0477E+006
4.0382E+006
3.0286E+006
2.0191E+006
1.0095E+006
0.000000000

Suspension system (An overview).

"Suspension," when discussing cars, refers to the use of front and rear springs to suspend a vehicle's "sprung" weight. The springs used on today's cars and trucks are constructed in a variety of types, shapes, sizes, rates, and capacities. Types include leaf springs, coil springs, air springs, and torsion bars. These are used in sets of four for each vehicle, or they may be paired off in various combinations and are attached by several different mounting techniques. The suspension system also includes shocks and/or struts, and sway bars.

Back in the earliest days of automobile development, when most of the car's weight (including the engine) was on the rear axle, steering was a simple matter of turning a tiller that pivoted the entire front axle. When the engine was moved to the front of the car, complex steering systems had to evolve. The modern automobile has come a long way since the days when "being self-propelled" was enough to satisfy the car owner. Improvements in suspension and steering, increased strength and durability of components, and advances in tire design and construction have made large contributions to riding comfort and to safe driving.

The suspension system has two basic functions, to keep the car's wheels in firm contact with the road and to provide a comfortable ride for the passengers. A lot of the system's work is done by the springs. Under normal conditions, the springs support the body of the car evenly by compressing and rebounding with every up-and-down movement. This up-and-down movement, however, causes bouncing and swaying after each bump and is very uncomfortable to the passenger. These undesirable effects are reduced by the shock absorbers.

Suspension main parts and types.

The main part of the suspension is the spring. The three types of springs used are the coil spring, leaf spring and torsion bar.

Coil springs and torsion bars are generally used in the front whereas leaf springs are generally used in the rear. Coil springs are generally

installed between the upper and lower control arms with the shock absorber mounted inside the spring. In some cases, the coil spring is mounted on top of the upper control arm and a spring tower formed in the front-end sheet metal. Coil springs come in many "rates" and can be used to change the handling and ride characteristics of a vehicle.

Leaf springs are made from layers of spring steel bolted together through the center of the leafs. This center bolt locates the spring to the axle housing and is attached to the housing with large U-bolts. The ends of the leaf spring are attached to the frame or body through a shackle that allows the spring to flex without tearing out. The leaf spring also acts as control arms to keep the axle housing in proper position.

Most trucks with a solid beam front end still use leaf springs on the front. Some cars use a single leaf spring, front and rear, transversely mounted. In other words, the springs are mounted 90 degrees to the center of the car.

Another important part is the hydraulic shock absorber. Something that has not changed too much since its use started sometime in the 1930's.

The operating principle of standard hydraulic shock absorbers is in forcing fluid through restricting openings in the valves. This restricted flow serves to slow down and control rapid movement in the car springs as they react to road irregularities. Usually, spring-loaded valves control fluid flow through the pistons. Hydraulic shock absorber automatically adapt to the severity of the shock. If the axle moves slowly, resistance to the flow of fluid will be light. If the axle movement is rapid or violent, the resistance is stronger, since more time is required to force fluid through the openings.

By these actions and reactions, the shock absorbers permit a soft ride over small bumps and provide firm control over spring action for cushioning large bumps. The double-acting units must be effective in both directions because spring rebound can be almost as violent as the original action that compressed the shock absorber.

Some vehicles came with a control that allowed the driver to select the ride type. By setting a control in the passenger compartment, a

motor on the top of the shock would rotate a set of different sized valves inside the shock to change the damping ability of the shock. There are usually three settings, Firm, Normal and Soft.

In an active suspension system there is a small sonar unit mounted in the bottom of the front bumper. The sonar unit sends a signal down onto the road and takes a "picture" of the road surface. This "picture" is sent to a control unit to automatically change the valving inside the shock to compensate for the road surface and maintain a smooth ride.

Another component of the suspension system is the sway bar. Some cars require stabilizers to steady the chassis against front-end roll and sway on turns. Stabilizers are designed to control this centrifugal tendency that forces a rising action on the side toward the inside of the turn. When the car turns and begins to lean over, the sway bar uses the upward force on the outer wheel to lift on the inner wheel, thus keeping the car more level.

Finally, we have the control arms. The primary job of the control arms is to mount the suspension to the frame or body of the vehicle and to allow the suspension to move and keep it in it's proper place. They come in all shapes and sizes and are specifically designed to maintain the geometry of the suspension in a wide range of movement. The most common problem is that the bushings at the body mounting points wear out causing unwanted movement at worst and a terrible squeaking noise at best. Next, the design of the front suspension of the buggy car will be put in plain words.

Front suspension design.

As an off-road car, the main features of the suspension should be to absorb high-shock forces due to the rough road, and have a high degree of freedom in the vertical direction of the ground; i.e to have high amplitude, so depending on these conditions I could come up with a front suspension design. One of the main challenges in designing the suspension is how and on which point should the suspension be connected to the car chassis, in a way that assure a free moving for the suspension in the (Z-direction) – the vertical direction to the ground –

while at the same time prevent the moving of the suspension in the (X and Y directions) of course relative to the body, with taking in consideration that these connection should be designing in a way that derive minimum forces on them due to the axial and bending forces which is transformed from the wheel to the axel to the connections, so the connections should be capable of standing these forces. For these reasons I used (working model) software, which help me a lot in simulating the movement of the car over a road-pump and the reaction of the suspension due to the pump, as the accompanied movie (avi file) shows, the results will be discussed later on this report.

The basic principle of the first design of the suspension is an integration of *TWO* [four-bar-linkage mechanisms], as shown in figure (4). The final dimensions of the bar connections still under study depending on the angle which should be set to the wheel, as these connection will play the main factor in determining the angles of the wheel.

The spring-damper mechanism is connected to a two brackets, one is fixed by welding to the chassis and the other is fixed also by welding to the lower frame of the suspension mechanism. The spring-damper is free to revolute parallel to its plane of movement, but limited to the bars connections length. By this type of connection the shear or bending force applied to the spring-damper would be minimum, which is a desired result, and the force applied will be in an axial form in the same direction of the spring-damper movement.

The axel is designed in a way that makes it possible for the wheel to revolute around a fixed axes relative to the suspension, this constraint permits a rotational (D.O.F) for the axel in a plane parallel to the lower frame plane (X-Y plane), the rotational movement is limited just to the constraints of the steering system which will be discussed later. The separator between the axel body and both the lower and upper frame bodies will be two axial roller bearings, which will permit the rotation of the axel with the least amount of friction force.

The type of connection between the bars and the lower and upper frame would be a plane bearings, which is fixed by screw and nuts, but the specific types of nuts and bearing will be determined when the front suspension reach it's final design.

The figure below shows the main parts of the suspension.

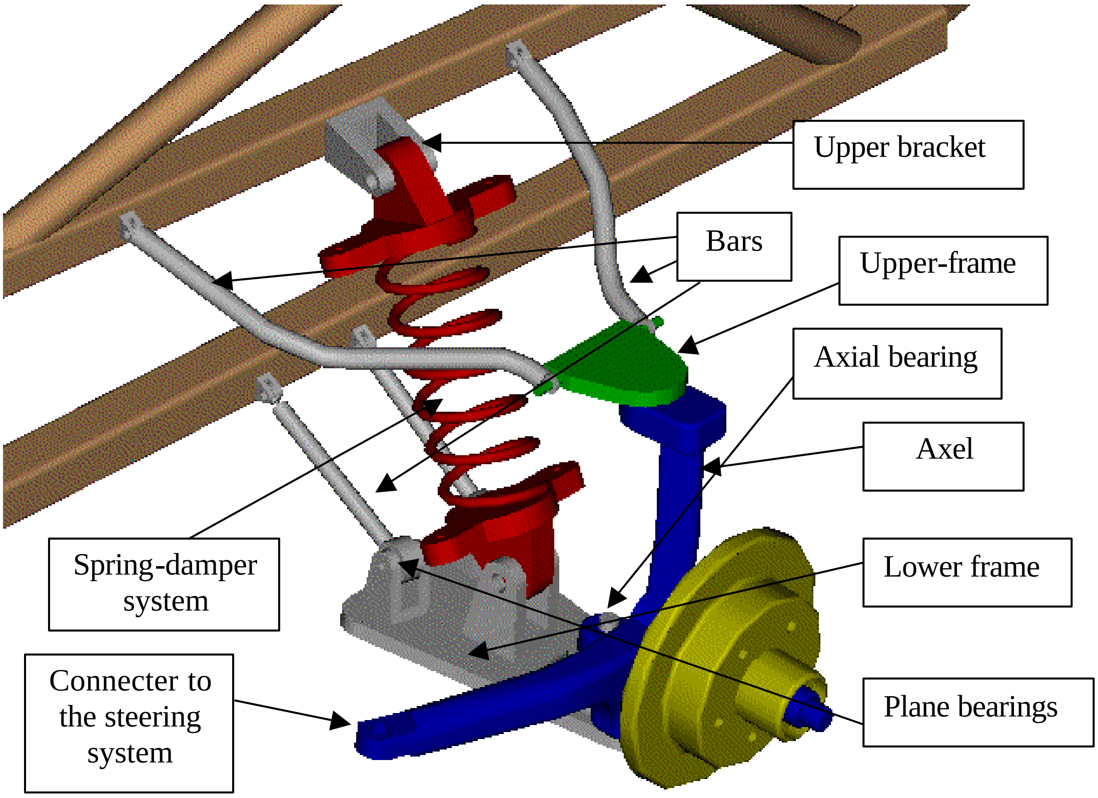
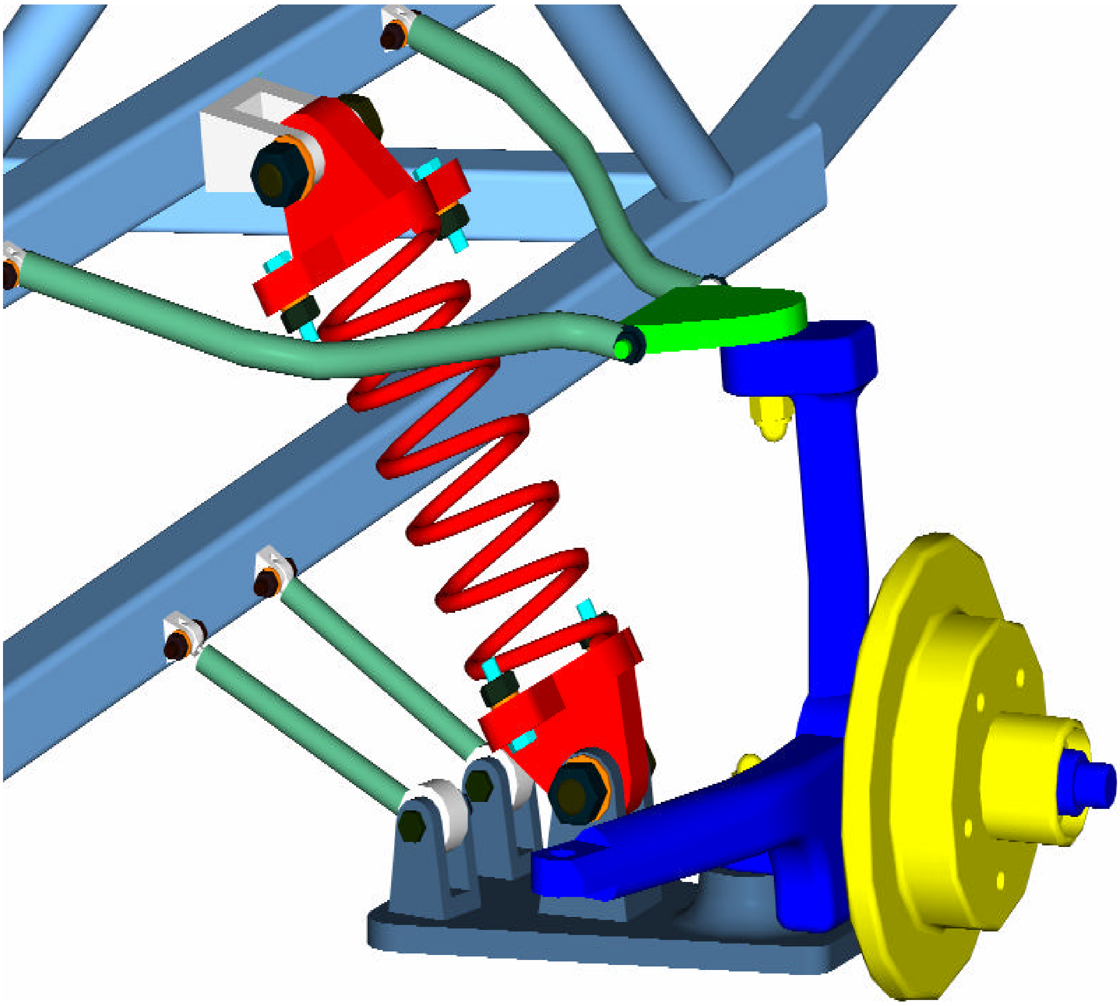


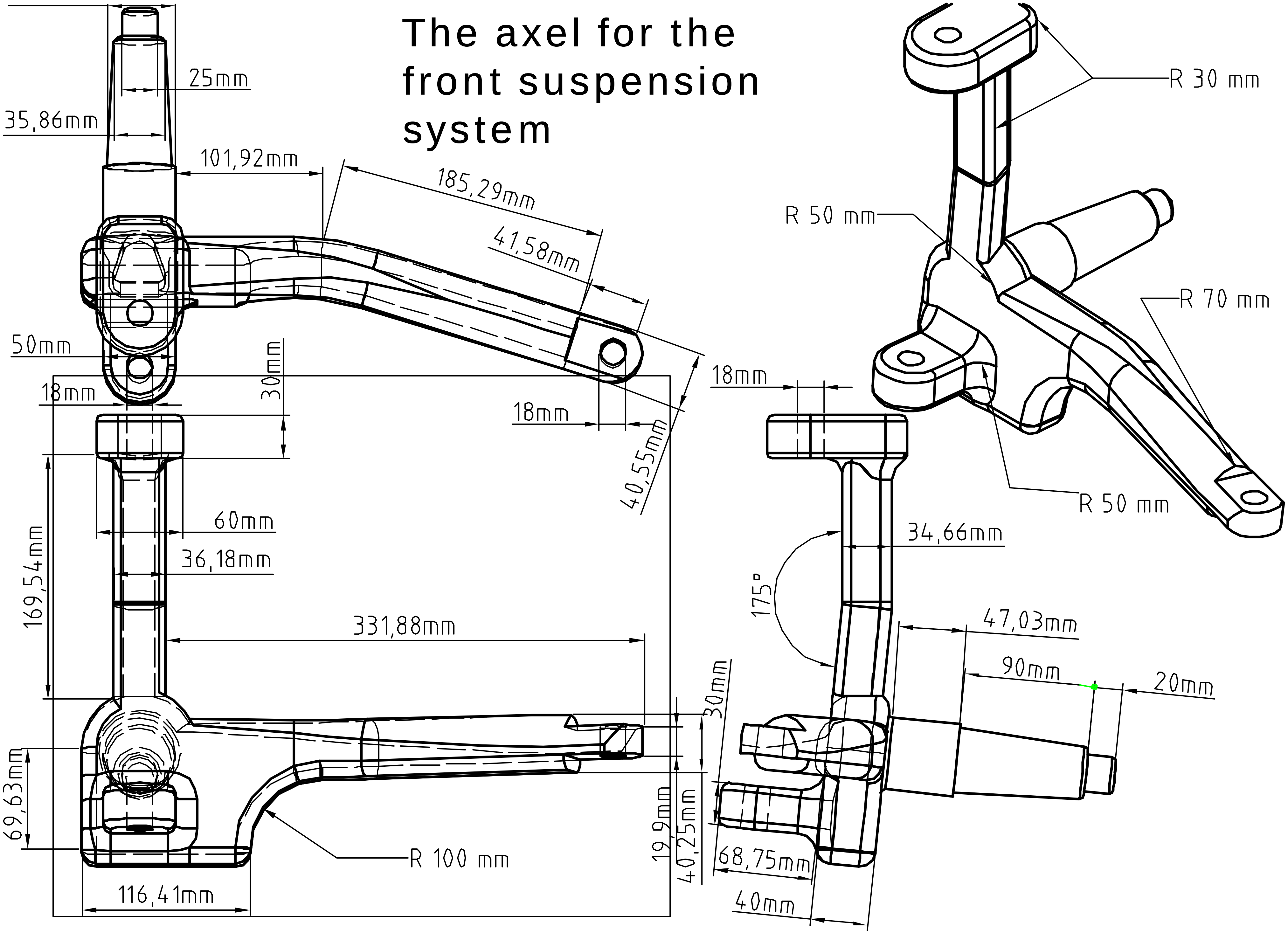
Figure (4)

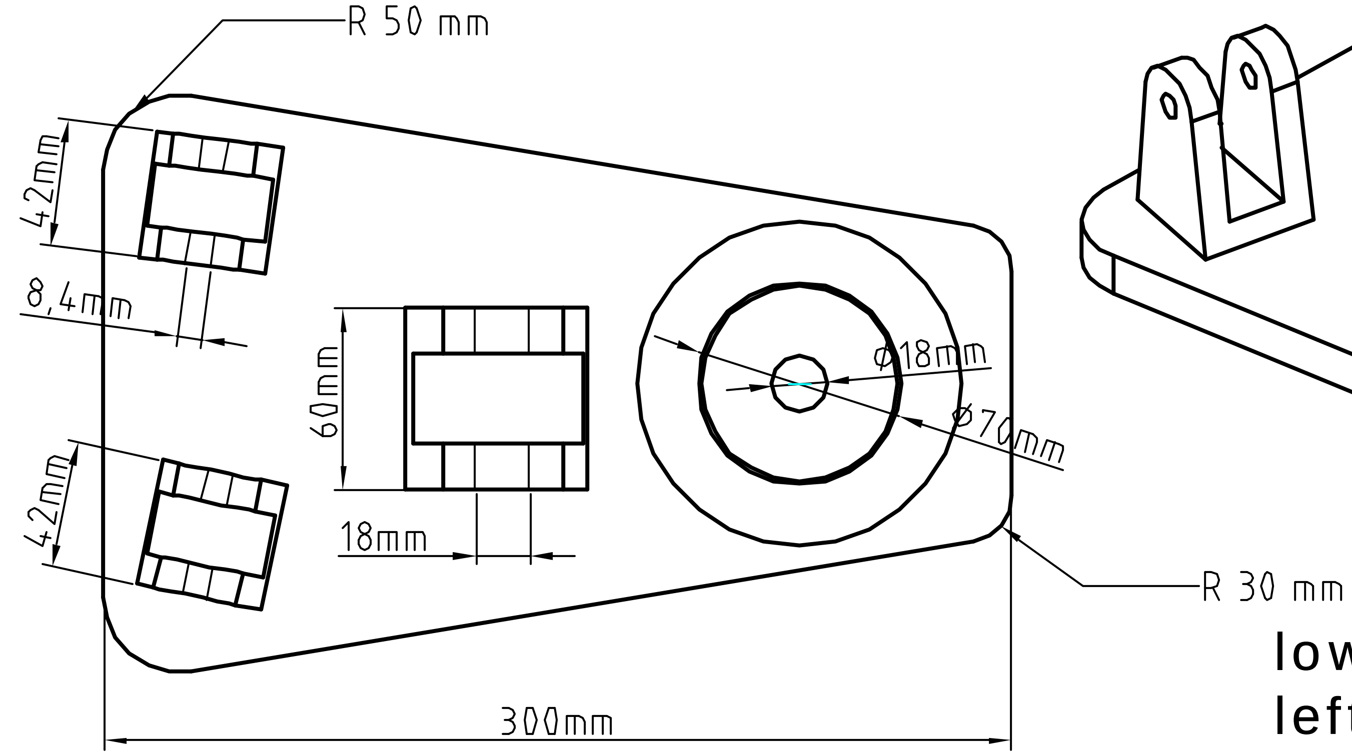
C.A.D DRAWINGS FOR THE FRONT SUSPENSION SYSTMEM

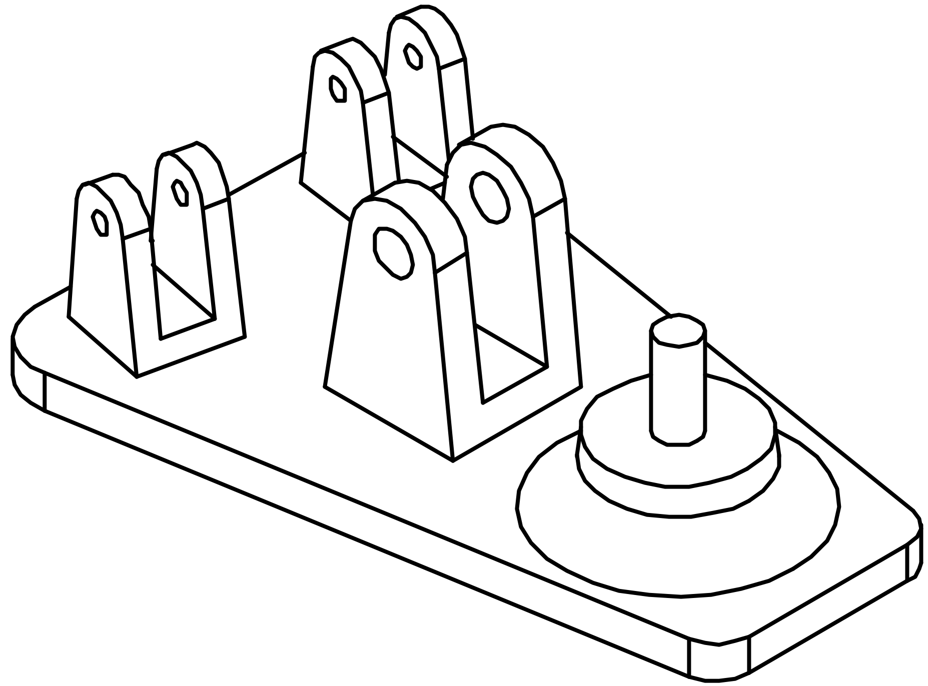
DETAILS
&
ASSEMBLIES



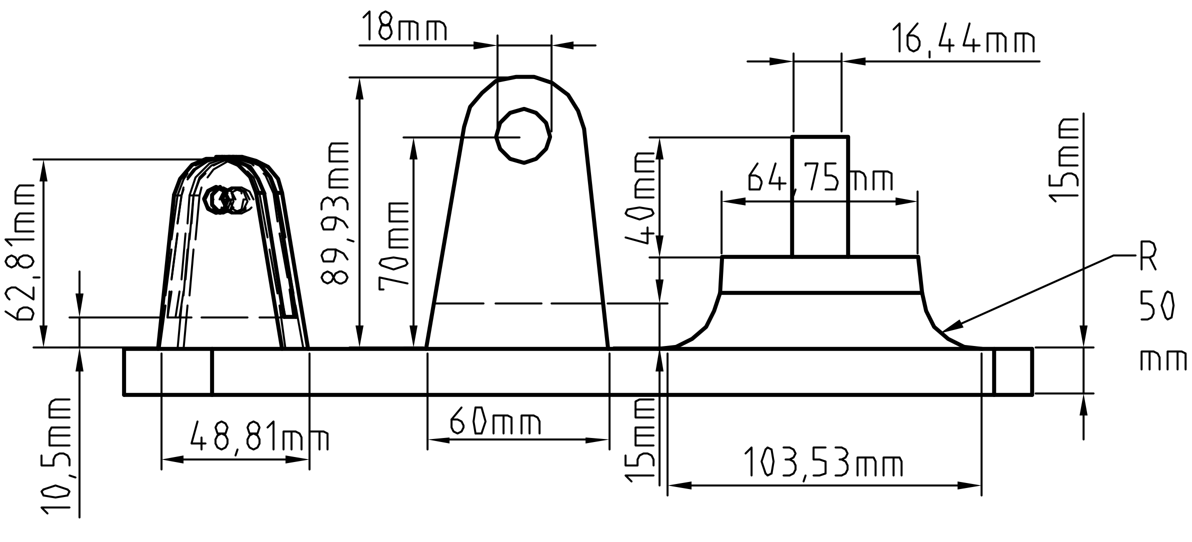
The axel for the front suspension system

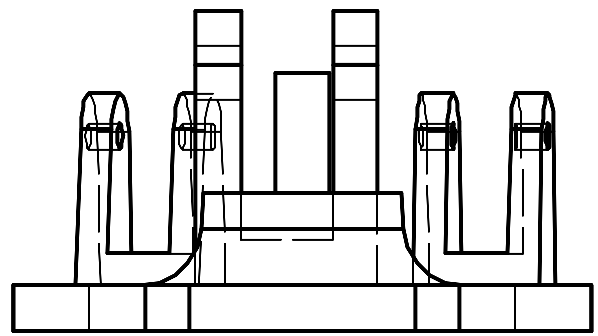




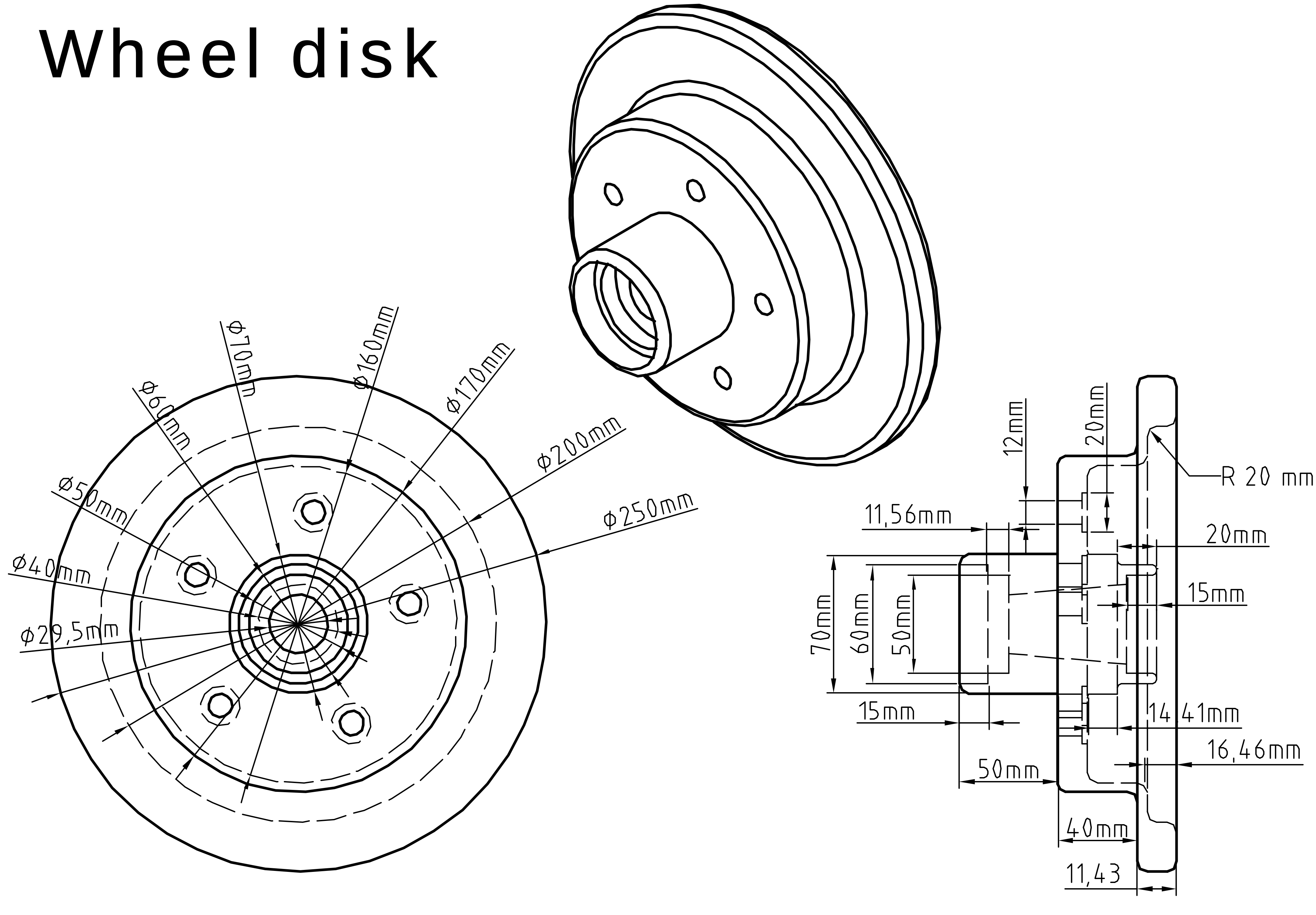


lower frame for the left suspension



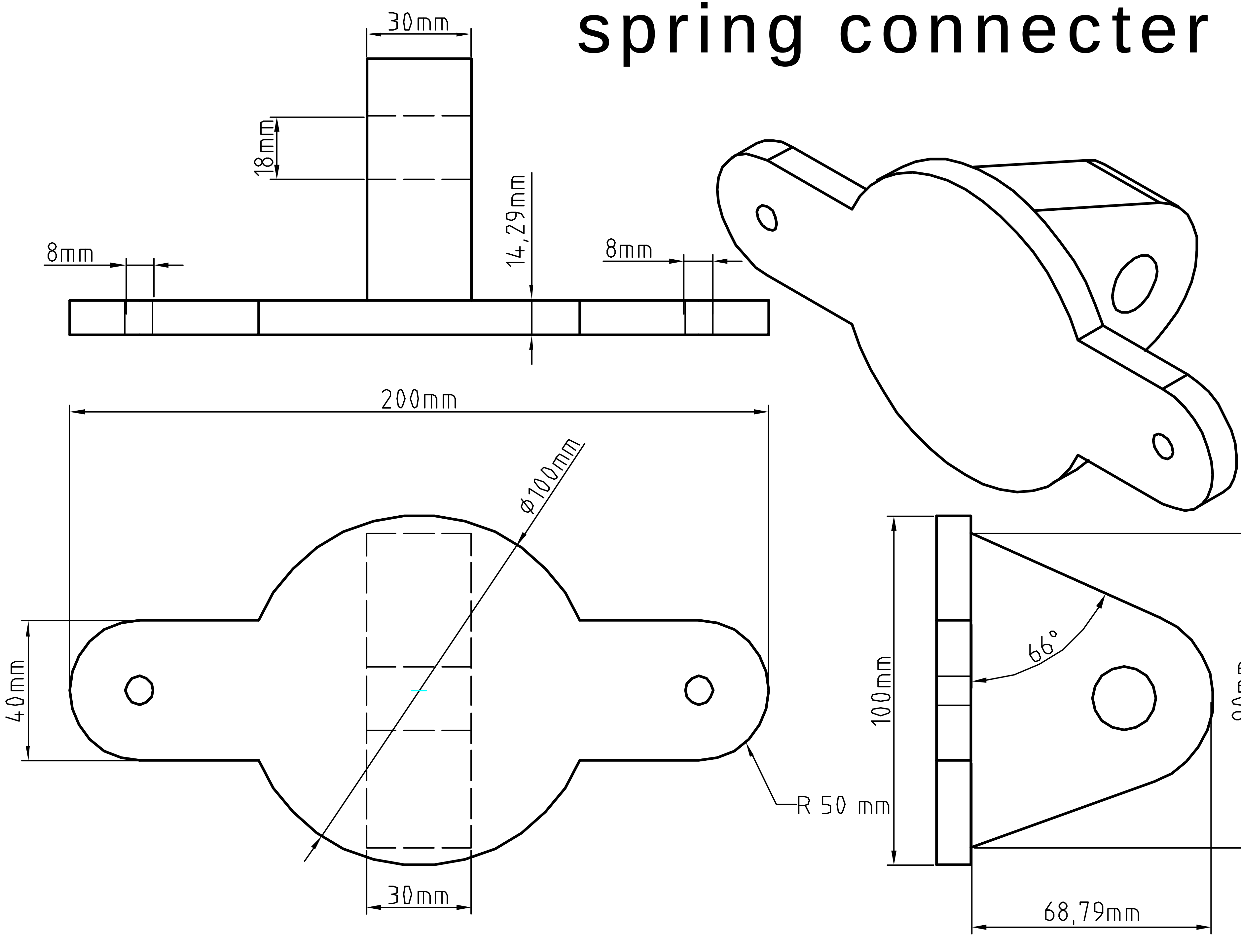


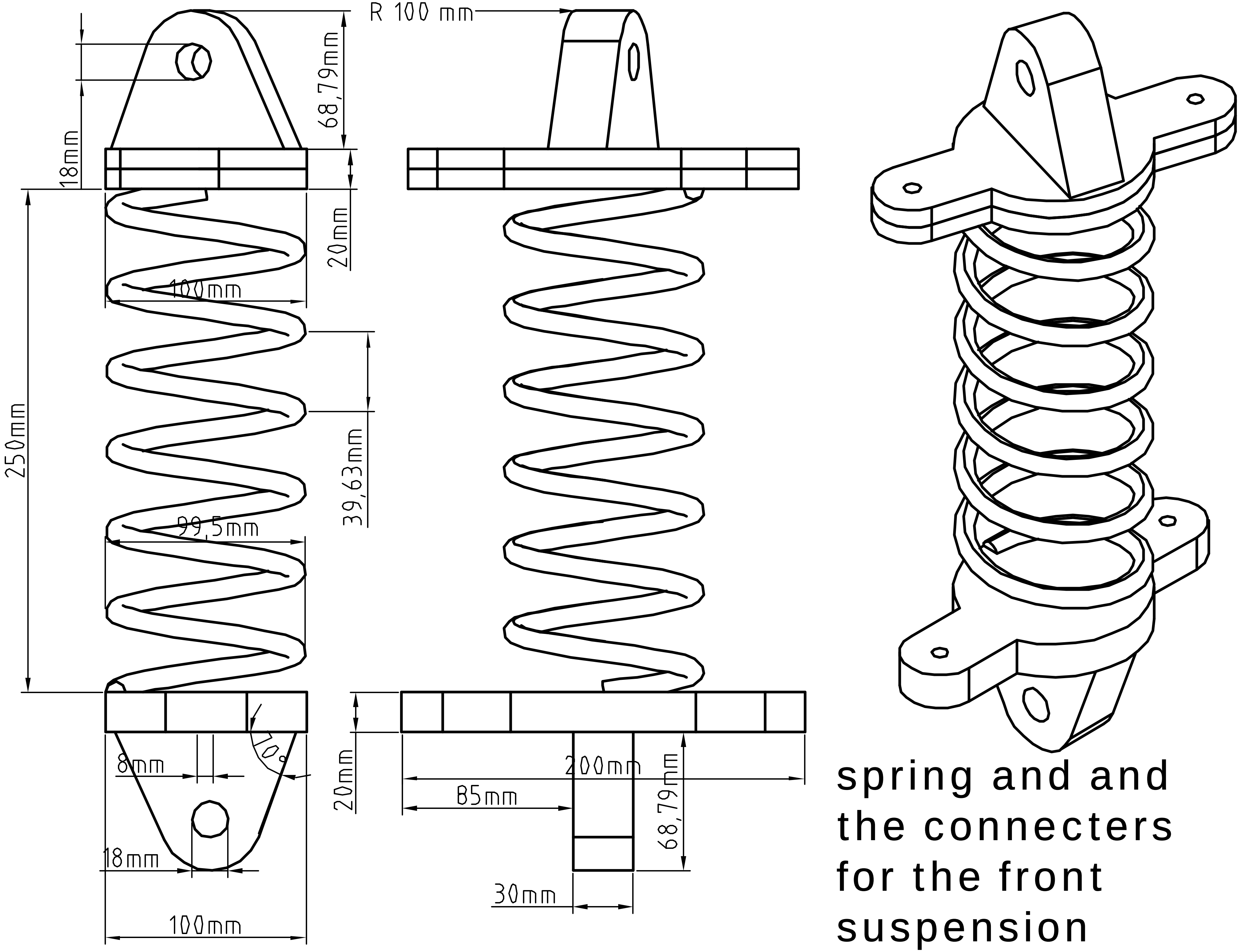
Wheel disk



ϕ70mm
ϕ160mm
ϕ60mm
ϕ170mm
ϕ200mm
ϕ50mm
ϕ250mm
ϕ40mm
ϕ29,5mm
12mm
20mm
R 20 mm
11,56mm
20mm
15mm
70mm
60mm
50mm
15mm
14,41mm
16,46mm
50mm
40mm
11,43

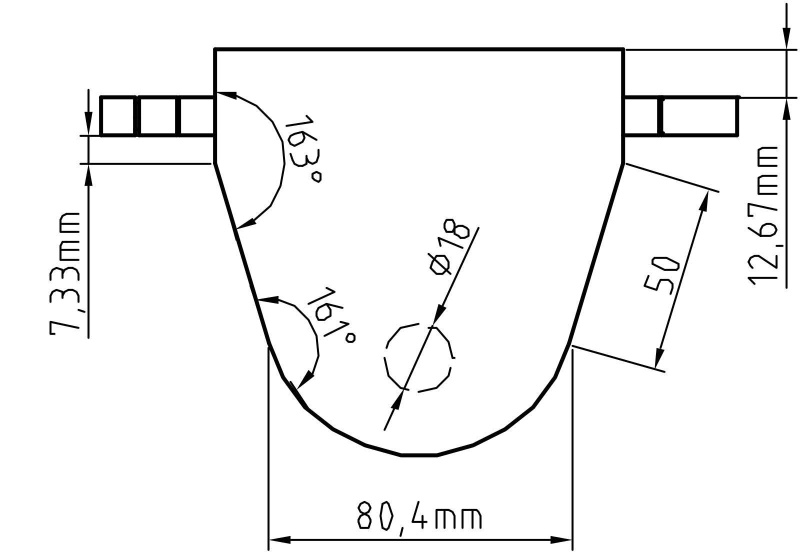
spring connecter

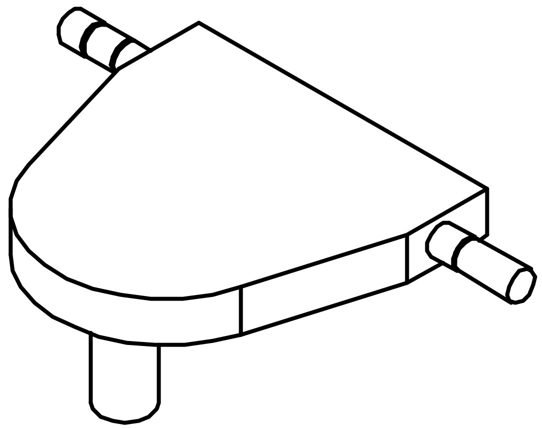


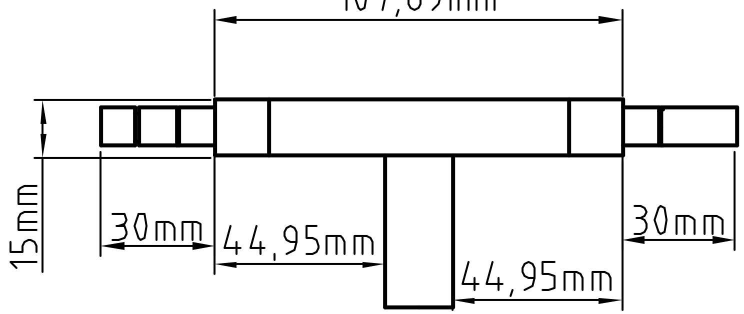


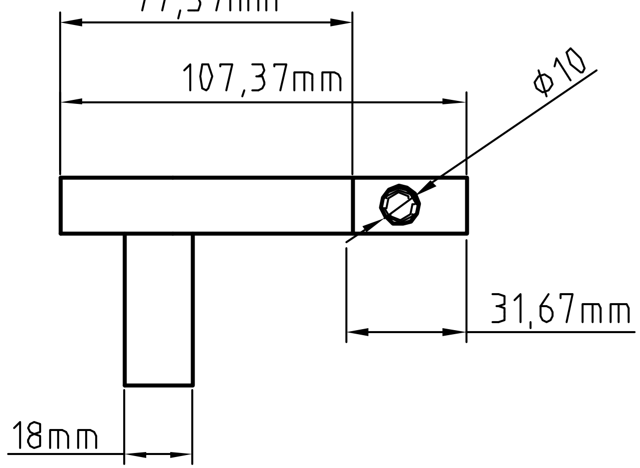
spring and and
the connecters
for the front
suspension

Upper frame for the front suspension





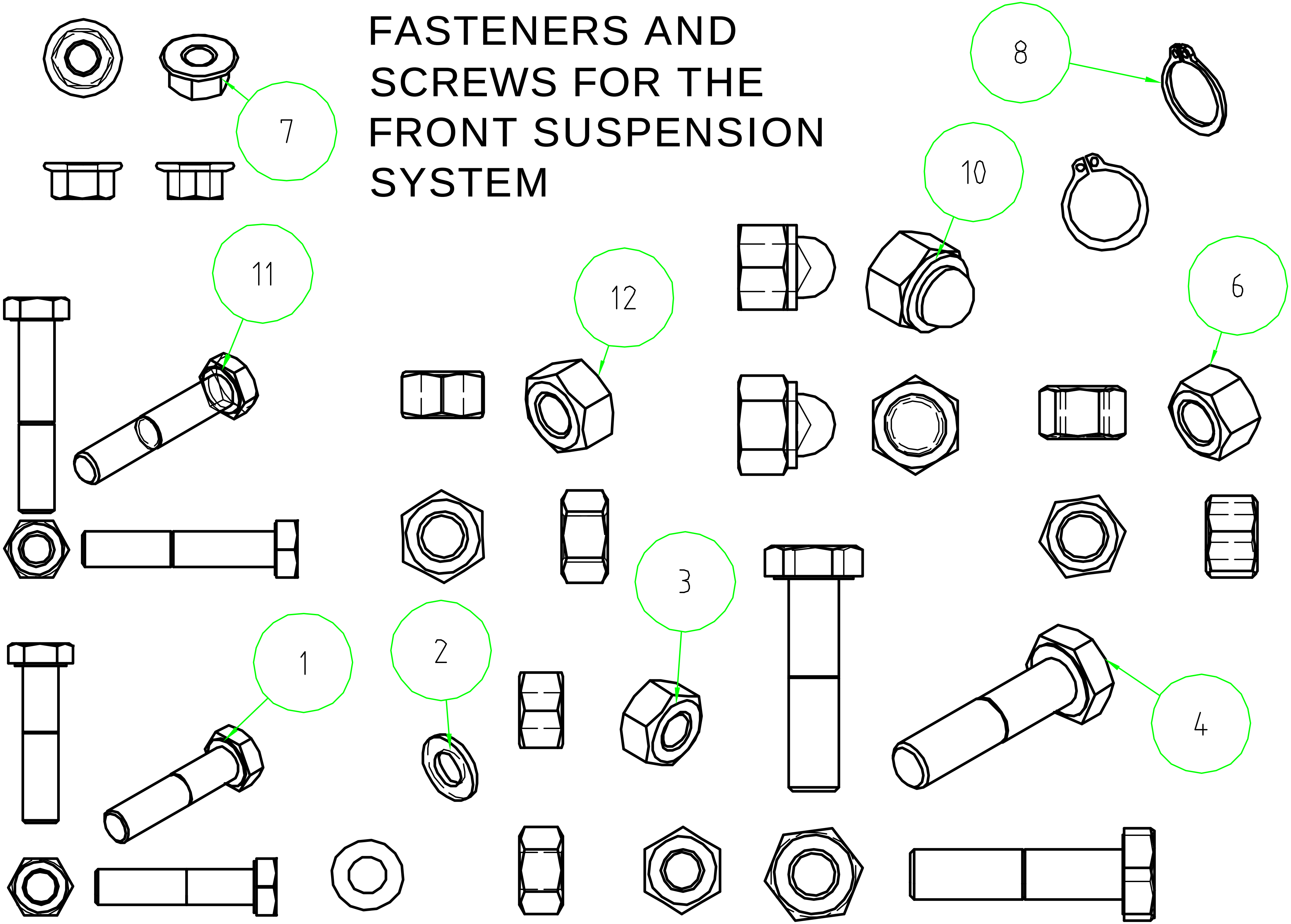




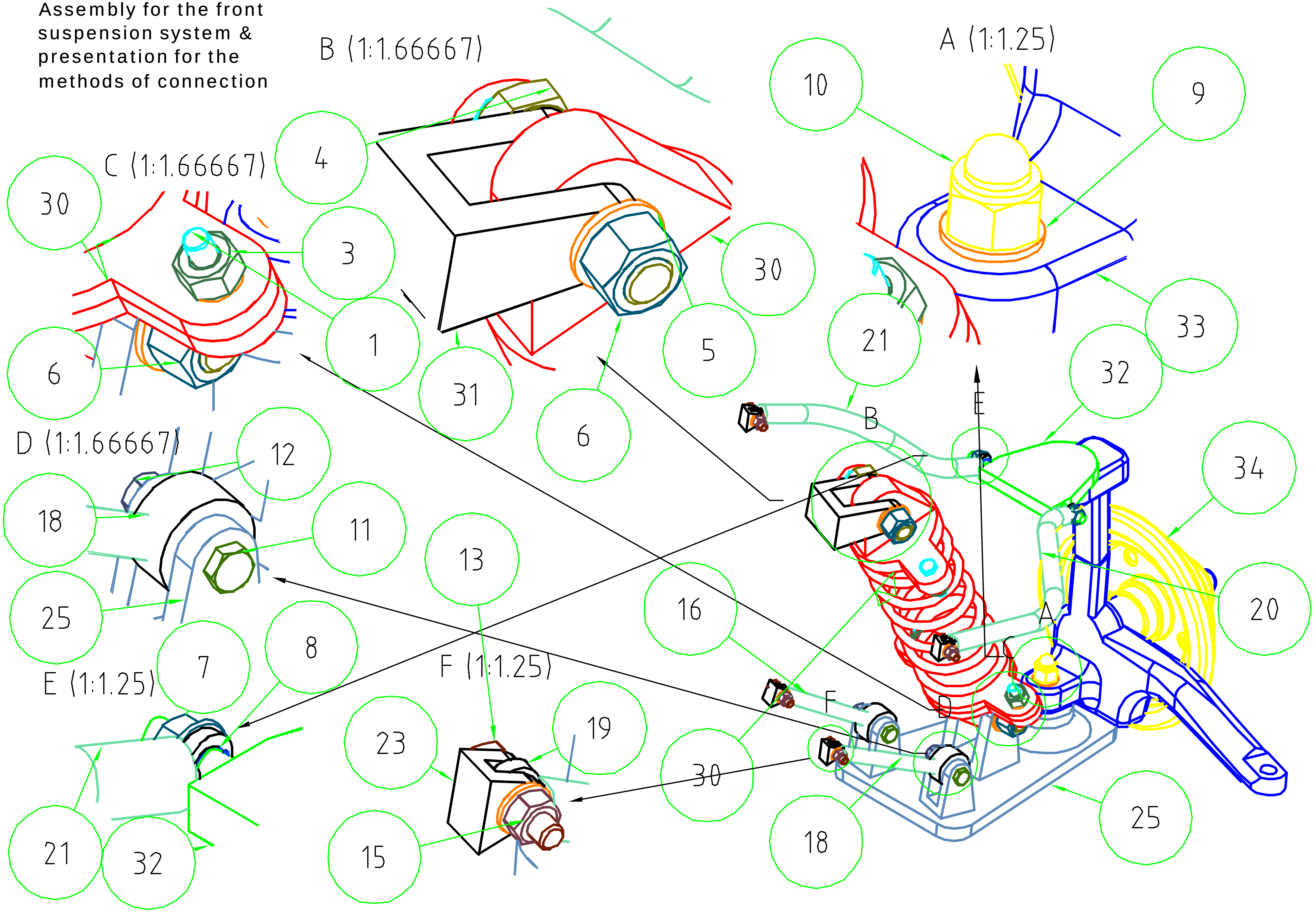
Bill of Material

Item	Qty	Description	Standard	Name
1	4	Hex-Head Bolt	ISO 8765 - M10 x 1 x 45	HEX-HEAD BOLT - ISO 8765 - M10 X 1 X 45
2	6	Washer	ISO 7089 - 10 - 140 HV	WASHER - ISO 7089 - 10 - 140 HV
3	4	Hex Nut	ISO 4775 - M12	HEX NUT - ISO 4775 - M12
4	2	Heavy Hex Screw (Regular Thread - Metric)	ANSI B18.2.3.3M - M20 x 2.5 x 85	HEAVY HEX SCREW (REGULAR THREAD
5	2	Washer	ISO 7089 - 20 - 140 HV	WASHER - ISO 7089 - 20 - 140 HV
6	2	Hex Nut	ISO 4033 - M20	HEX NUT - ISO 4033 - M20
7	2	Hex Nut with Flange	ISO 4161 - M10	HEX NUT WITH FLANGE - ISO 4161 - M10
8	2	External Type-3AM1	ANSI B27.7 - 10	EXTERNAL TYPE-3AM1 - ANSI B27.7 - 10
9	2	Washer	ISO 7089 - 14 - 140 HV	WASHER - ISO 7089 - 14 - 140 HV
10	2	Hexagon Domed Cap Nuts	DIN 986 - M16	HEXAGON DOMED CAP NUTS - M16
11	2	Hex-Head Bolt	ISO 4014 - M10 x 55	HEX-HEAD BOLT - ISO 4014 - M10 X 55
12	2	Hex Nut	ISO 4033 - M10	HEX NUT - ISO 4033 - M10
13	4	Hex-Head Bolt	ISO 4017 - M8x30	HEX-HEAD BOLT - ISO 4017 - M8X30
14	4	Washer	ISO 7089 - 8 - 140 HV	WASHER - ISO 7089 - 8 - 140 HV
15	4	Hex Nut	ISO 4032 - M8	HEX NUT - ISO 4032 - M8
16	1	Bar	ISO 1035/1 - 16	BAR - ISO 1035/1 - 16_1
18	1	Bar	ISO 1035/1 - 16	BAR - ISO 1035/1 - 16_2
19	6	Lifting Eye Bolt	GOST 4751-73 - M 12	LIFTING EYE BOLT - GOST 4751-73
20	1	connect the upper frame with the chassis		front upper connecting rod
21	1	connect the upper frame with the chassis		rear upper connecting rod
25	1	lower frame		PART1
26	1	spring connecter		SPRING-CONNECTER
33	1	AXEL		AXEL
34	1	WHEEL DISK		PART2
30	1	SPRING		SPRING102
31	1	SPRING JOINT		UPPER-BRACKET
32	1	UPPER FRAME		UPPER-FRAME
23	4	connect the rods to the chassis		ARM-BRACKET
24	1	Hot finished hollow section	ISO 657/14 - 50x50x3.2	ISO 657/14 - 50X50X3.2_1

FASTENERS AND SCREWS FOR THE FRONT SUSPENSION SYSTEM



Assembly for the front suspension system & presentation for the methods of connection



Simulation results

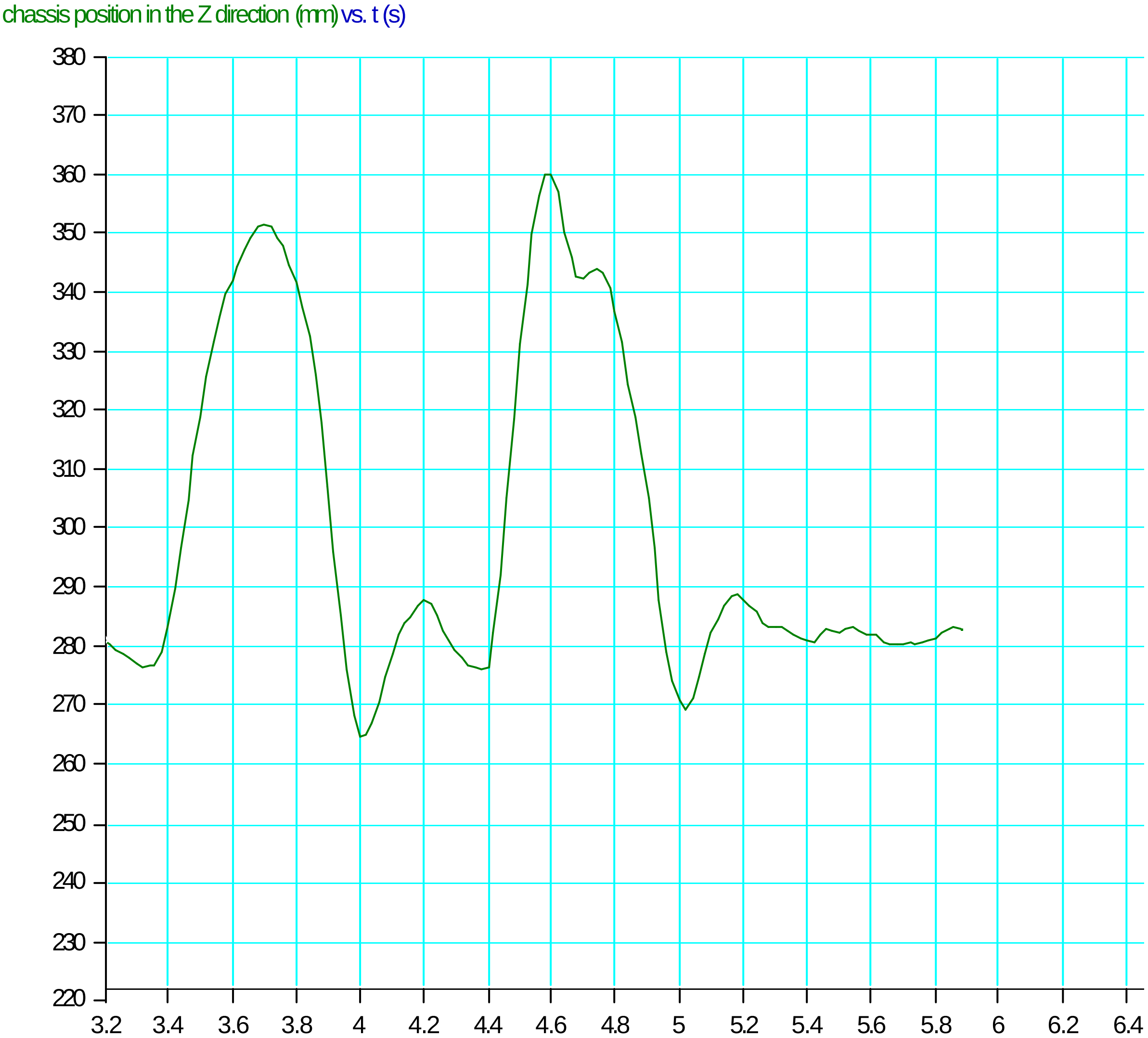
Simulation (1)

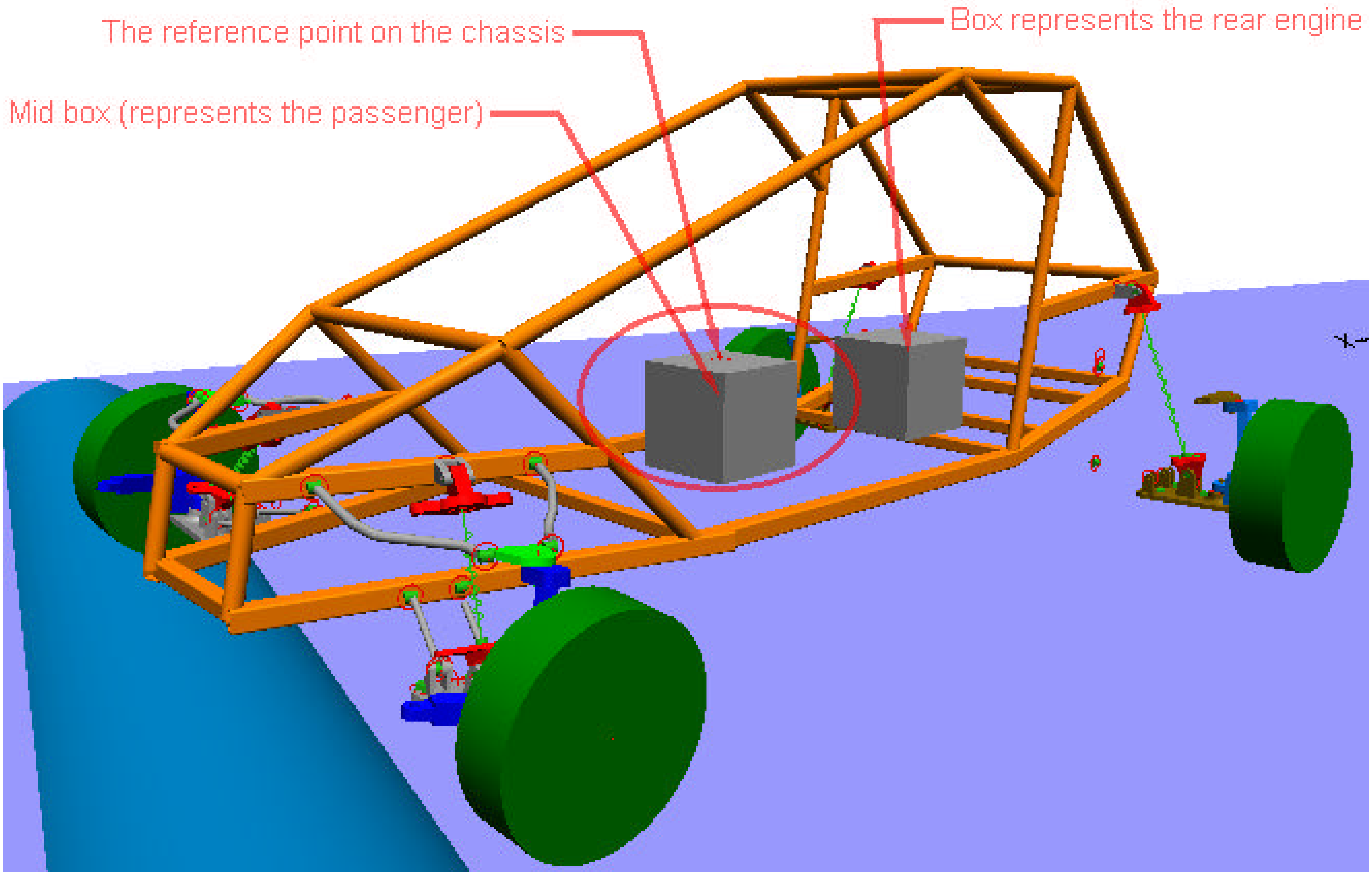
Simulation settings:

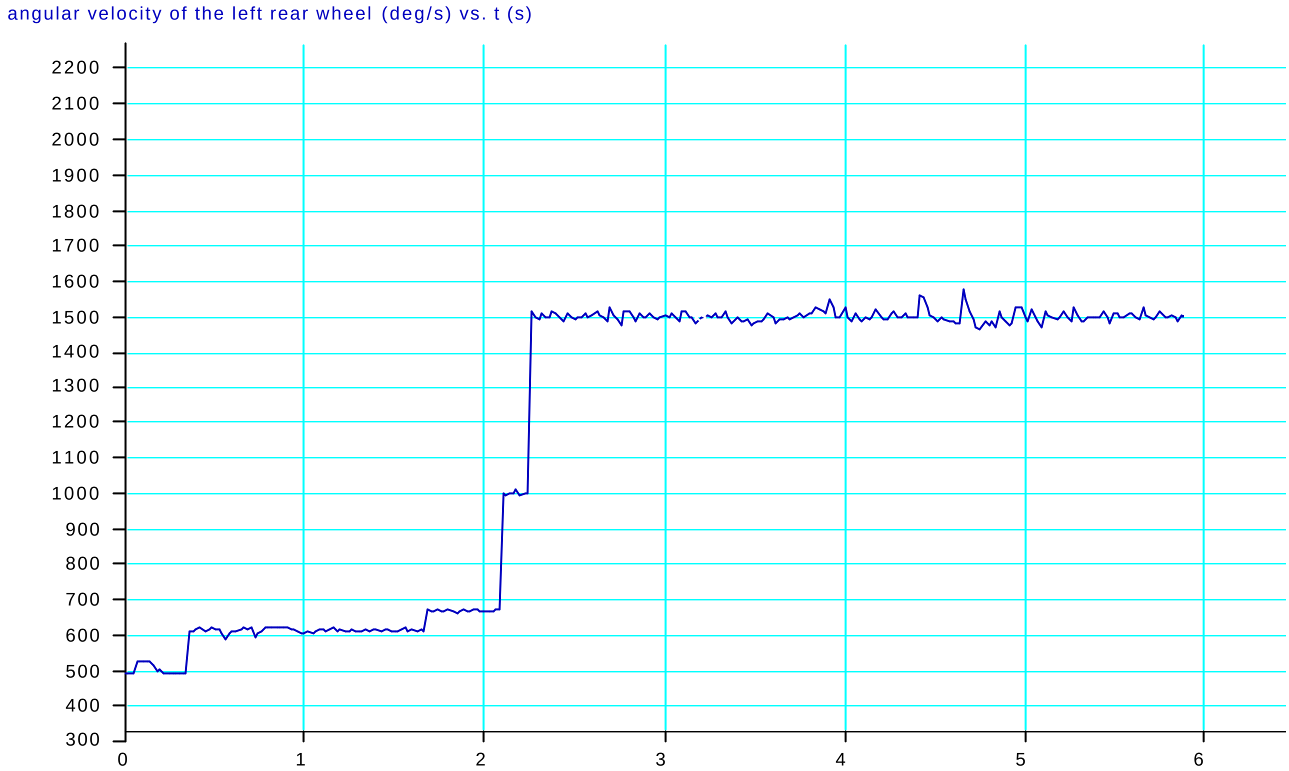
Front spring stiffness (k): 80 KN/m
Front spring damping coefficient (c): 3000 kg/s
Natural front spring length: 0.26 m
Rear spring stiffness (k): 80 KN/m
Rear damping coefficient (C): 2500 kg/s
Natural rear spring length: 0.48 m
Deriving force: a motor connects the two rear wheels and gives a starting velocity of 500 deg/s at the start of simulation, and reach a constant speed of 1500 deg/s at the 2.3 sec.
***Note: (the motor velocity is controlled during the simulation by an input controller slider).**
The start time of the movie, which will be the start time for the graphs and analysis, is 3.2 sec.
The chassis mass: 98 kg.
The rear box (represent the motor) mass: 200 kg.
The mid box represents the passenger and other car accessories mass: 500 kg.
Wheels coefficient of friction: 0.5
Wheels coefficient of restitution: 0.1
Rear wheel mass: 15 kg
Front wheel mass: 10 kg
Rear wheel dimensions: (diameter: 0.5 m) (height: 0.15m)
Front wheel dimensions: (diameter: 0.45 m) (height: 0.125 m).
Road pump height: 0.17 m
Road pump length: 0.6 m

Data analysis:

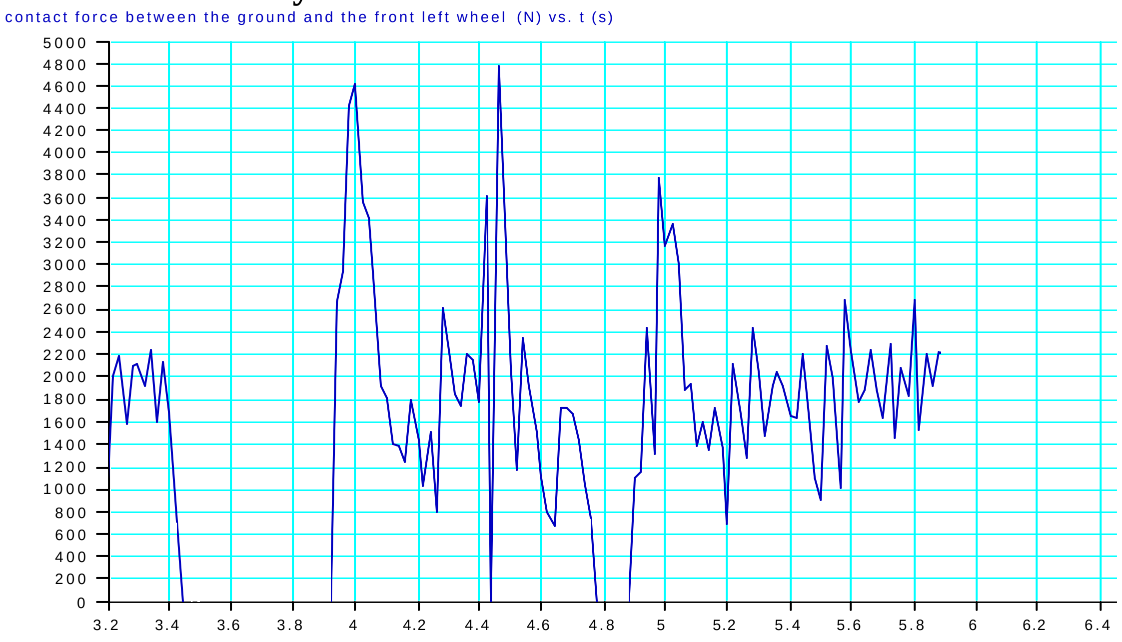
The following graph shows the change in the chassis position in the direction perpendicular to the road as it moves across the road pump. The reference point, which the altitude is measured on it, is a point on the upper surface of the mid box, which is rigid relative to the chassis.




The reference point on the chassis
Box represents the rear engine
Mid box (represents the passenger)



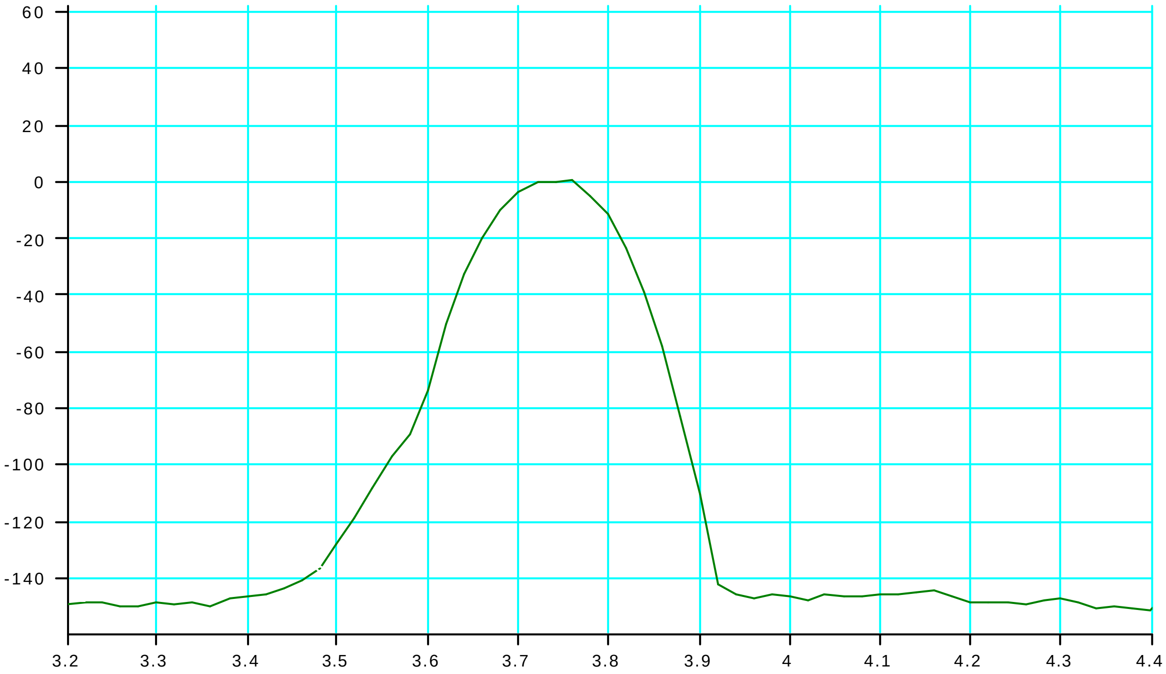
As it could be seen from the above graph that angular velocity is almost constant from the time 3.2 sec to the time 5 sec which is the time of the movie and the analysis.



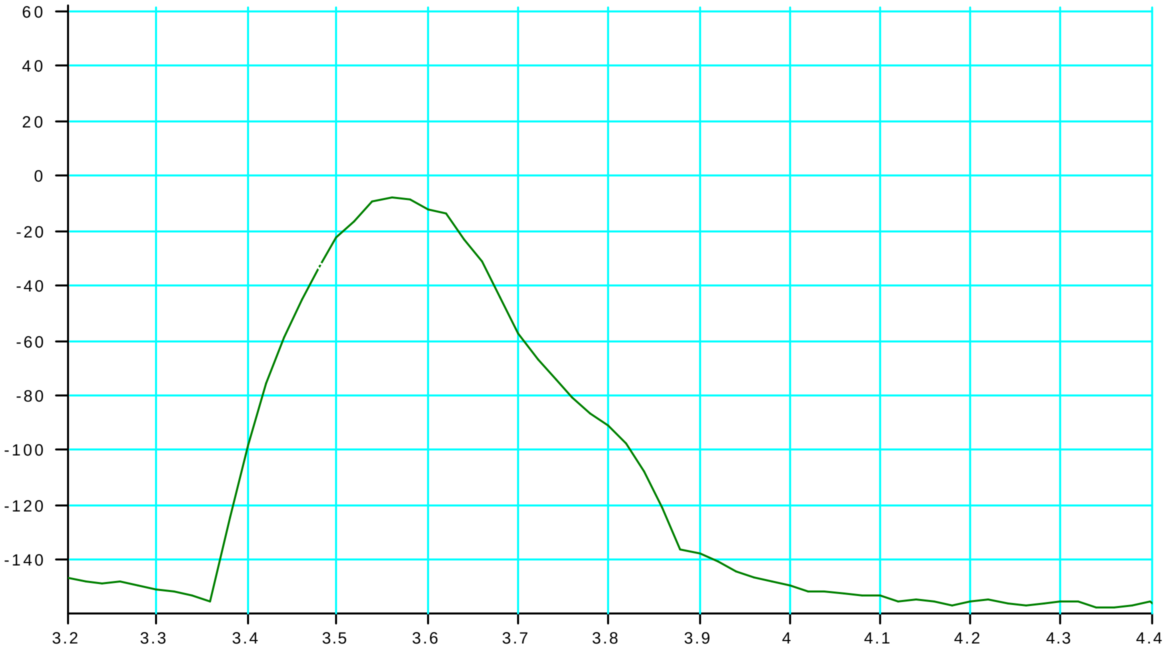
Note: the zero contact force from (3.4-3.9) sec, because the meter didn't measure the contact force between the pump and the wheel as the pump didn't consider a part from the ground

These two graphs represent the movement of the right and left lower frames of the front suspensions, as it could be seen from the two graphs that the right suspension start rising first because the car was set to move across the pump at an angle of 30 degree, (refer to the movie). Also the rising velocity of the right frame is more than in the left frame, (the right frame curve have high gradient in the rising curve). The amplitude for both curves almost the same, about (150 mm), which represents also the amplitude of the wheel as both the wheel and the lower frame connected rigidly in the Z-direction.

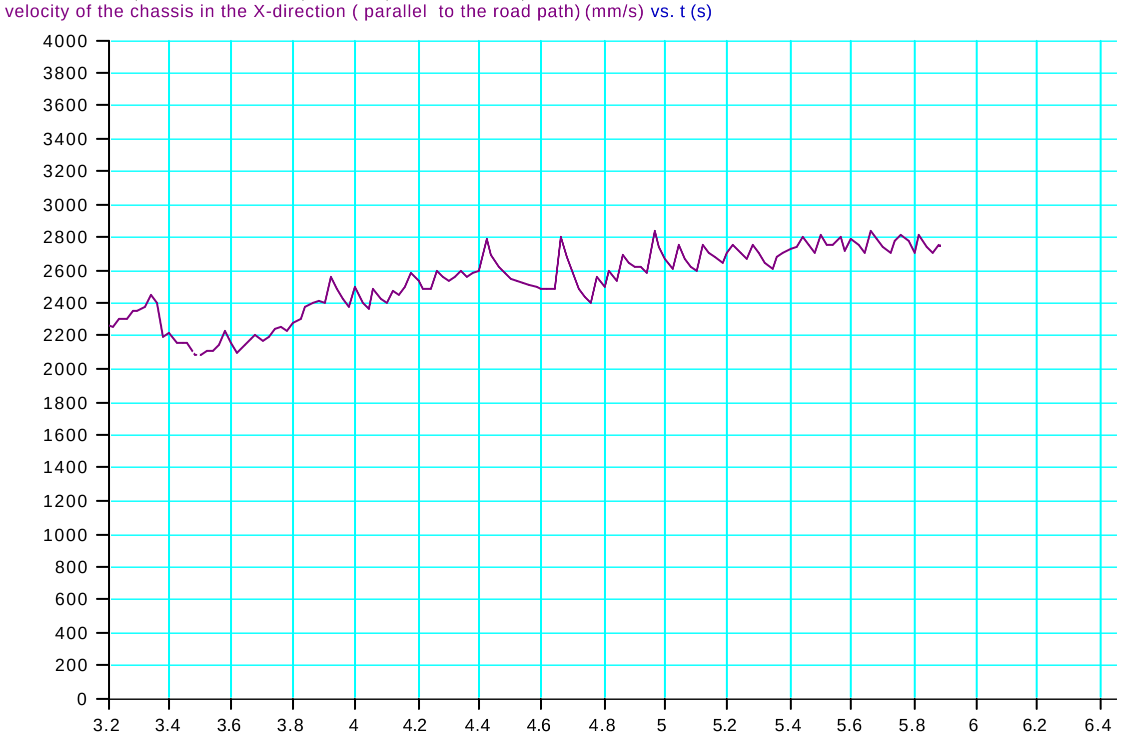
lower frame of the left front suspension positon in the z direction (mm) vs. t (s)

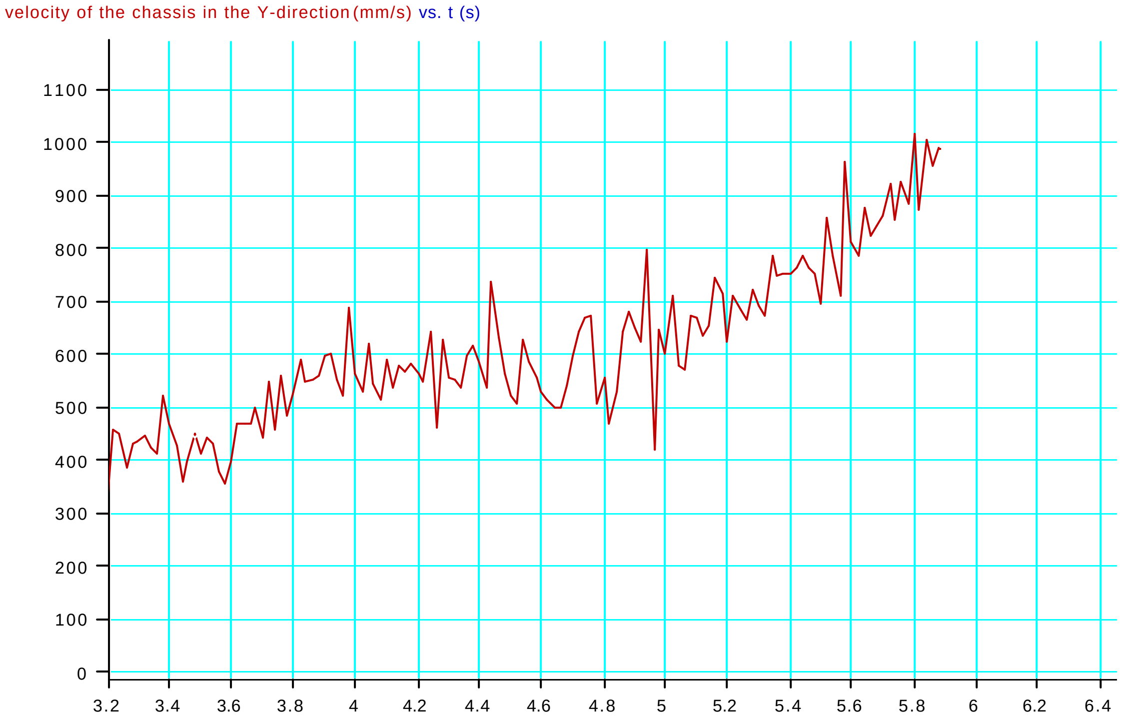


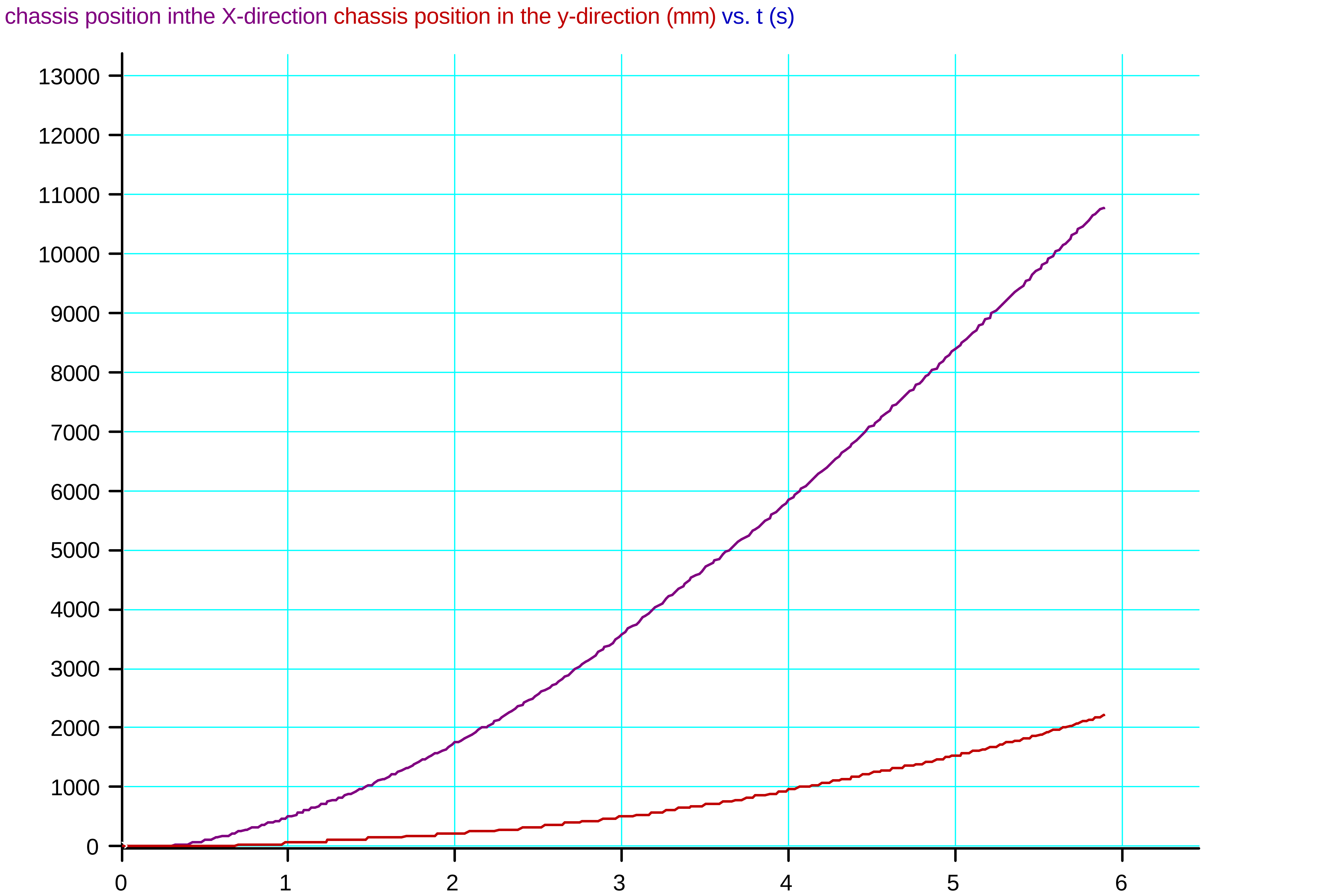
lower frame of the righ front suspension positon in the z direction (mm) vs. t (s)

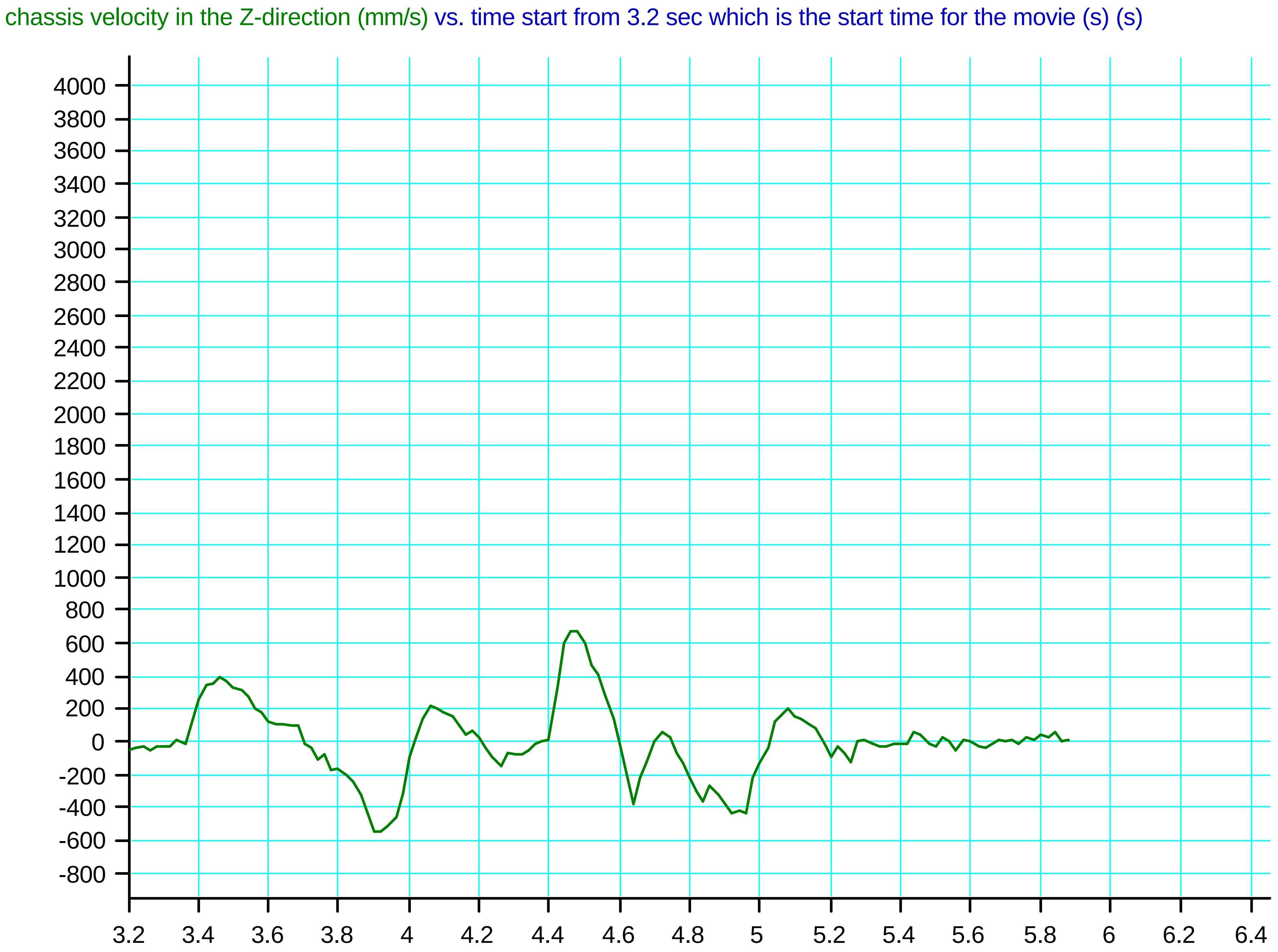


This graph shows the velocity of the car, which is almost constant around (2600 mm/s) or (9.4 km/h)

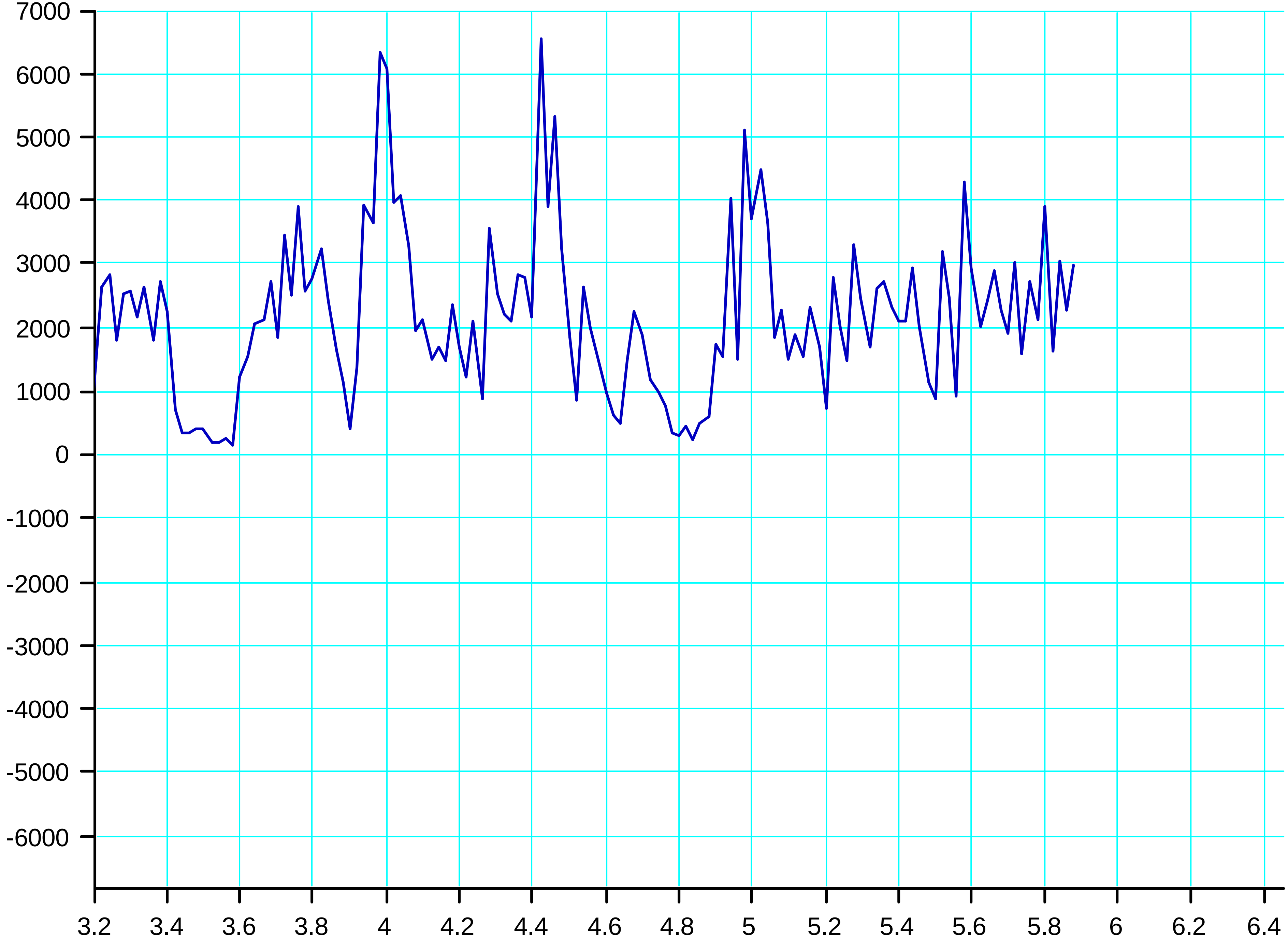




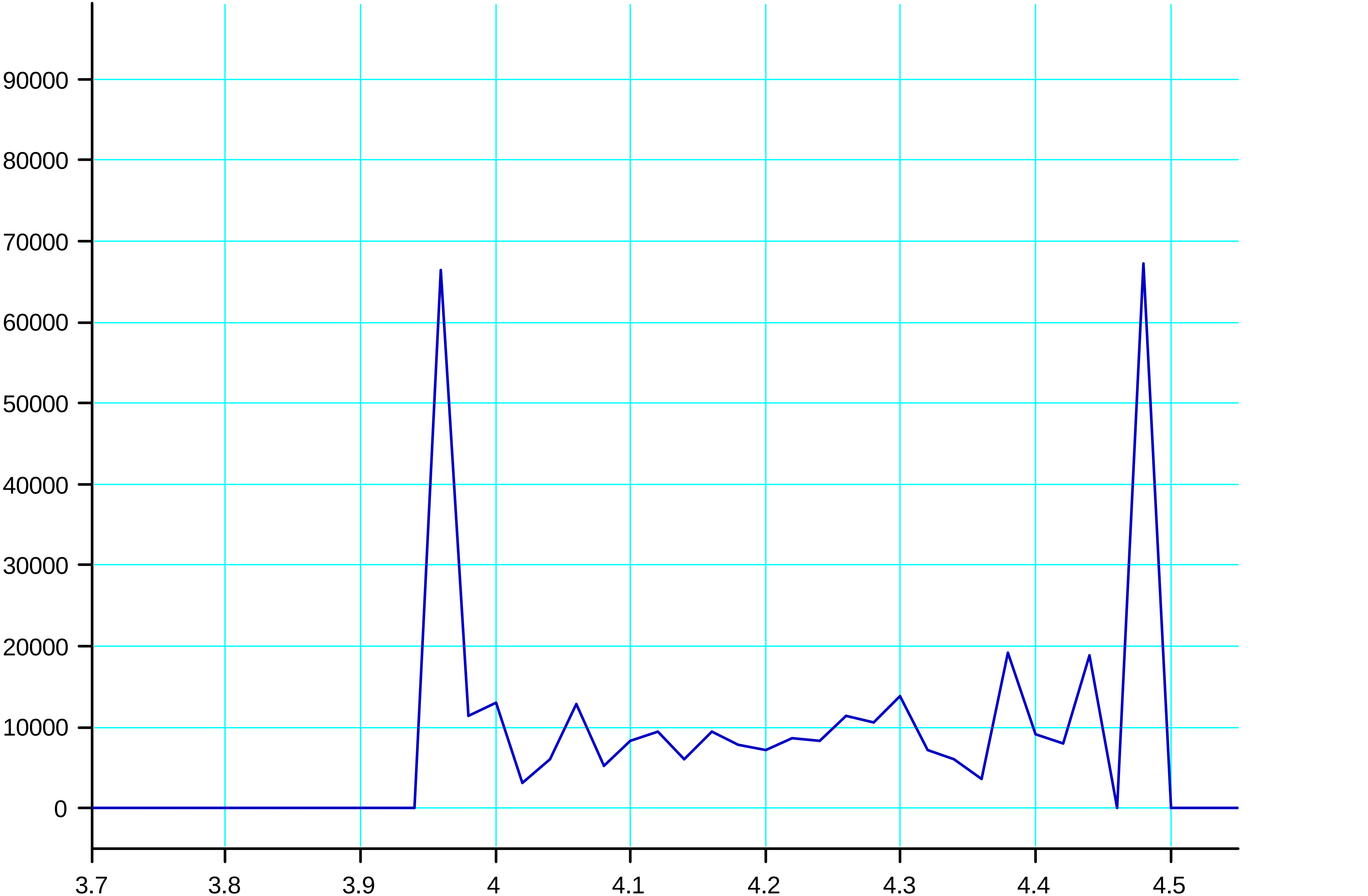

chassis position inthe X-direction chassis position in the y-direction (mm) vs. t (s)
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
1
2
3
4
5
6

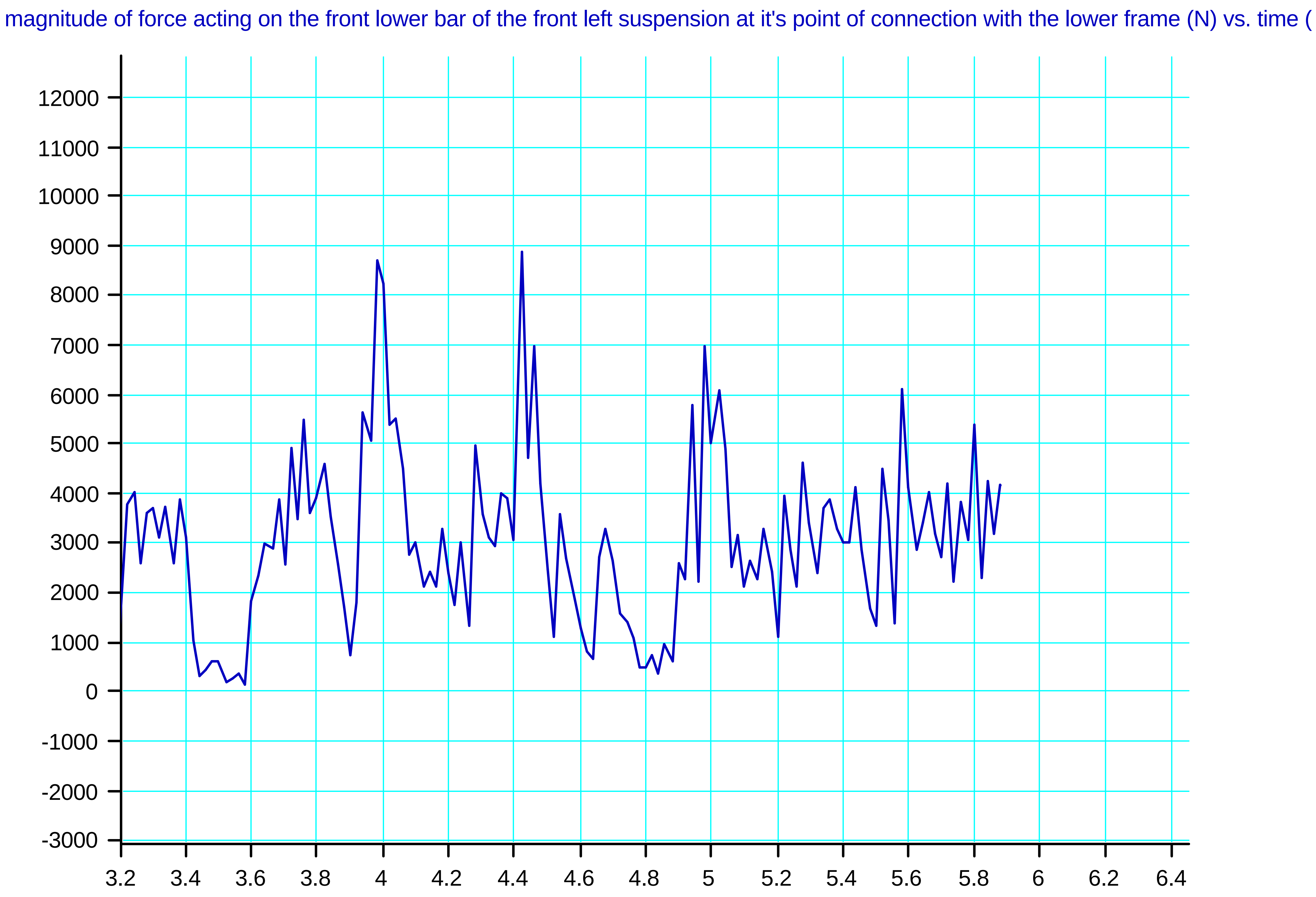

chassis velocity in the Z-direction (mm/s) vs. time start from 3.2 sec which is the start time for the movie (s) (s)
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
-400
-600
-800
3.2
3.4
3.6
3.8
4
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4

Magnitude of force acting on the front axel of the left suspension at it's point of connection with the lower frame (N) vs. time (s)



Impulse magnitude between the left front wheel and the ground (kg mm/s) vs. t (s)




magnitude of force acting on the front lower bar of the front left suspension at it's point of connection with the lower frame (N) vs. time (
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
3.2
3.4
3.6
3.8
4
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4

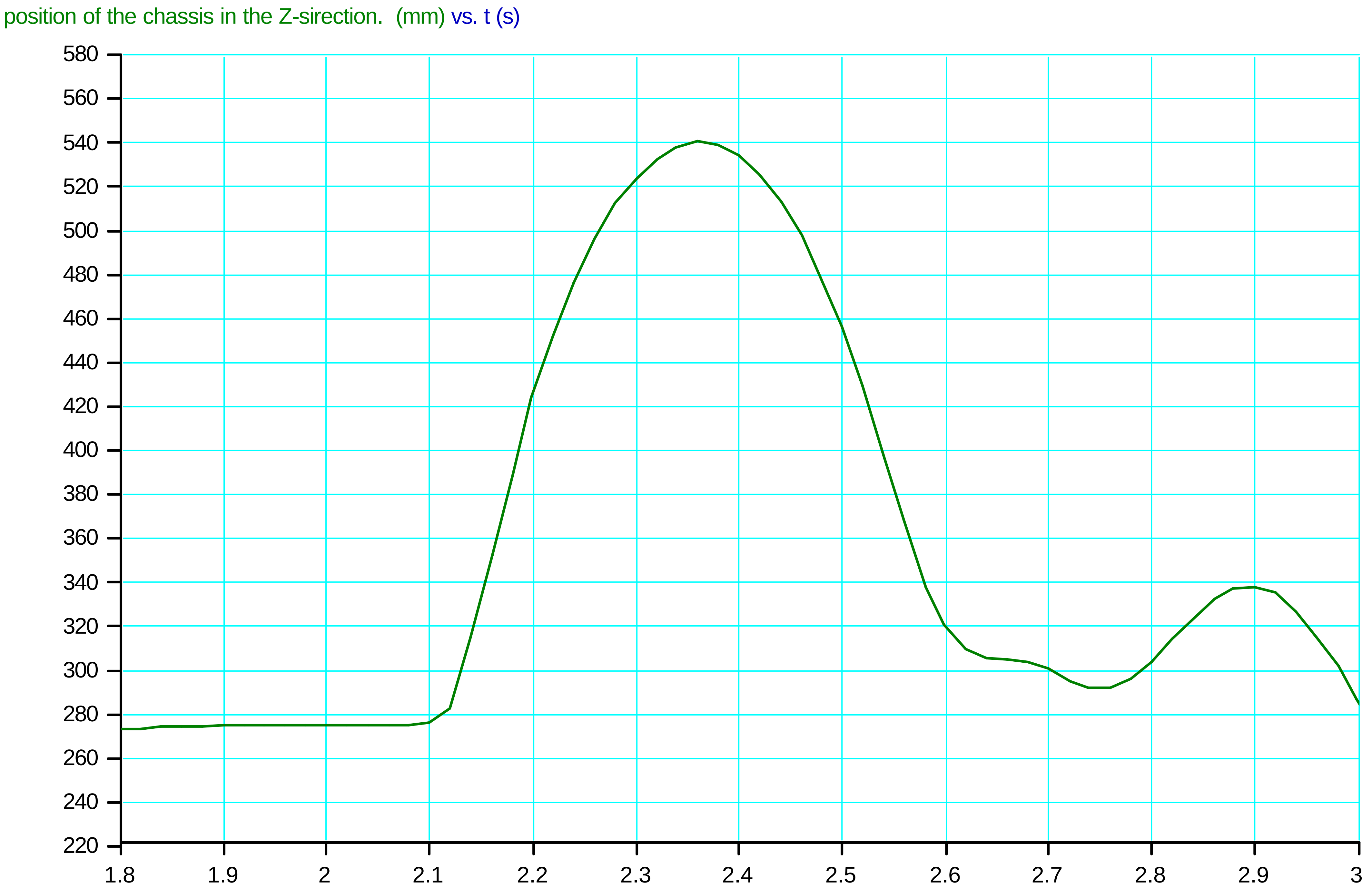
Simulation (2)

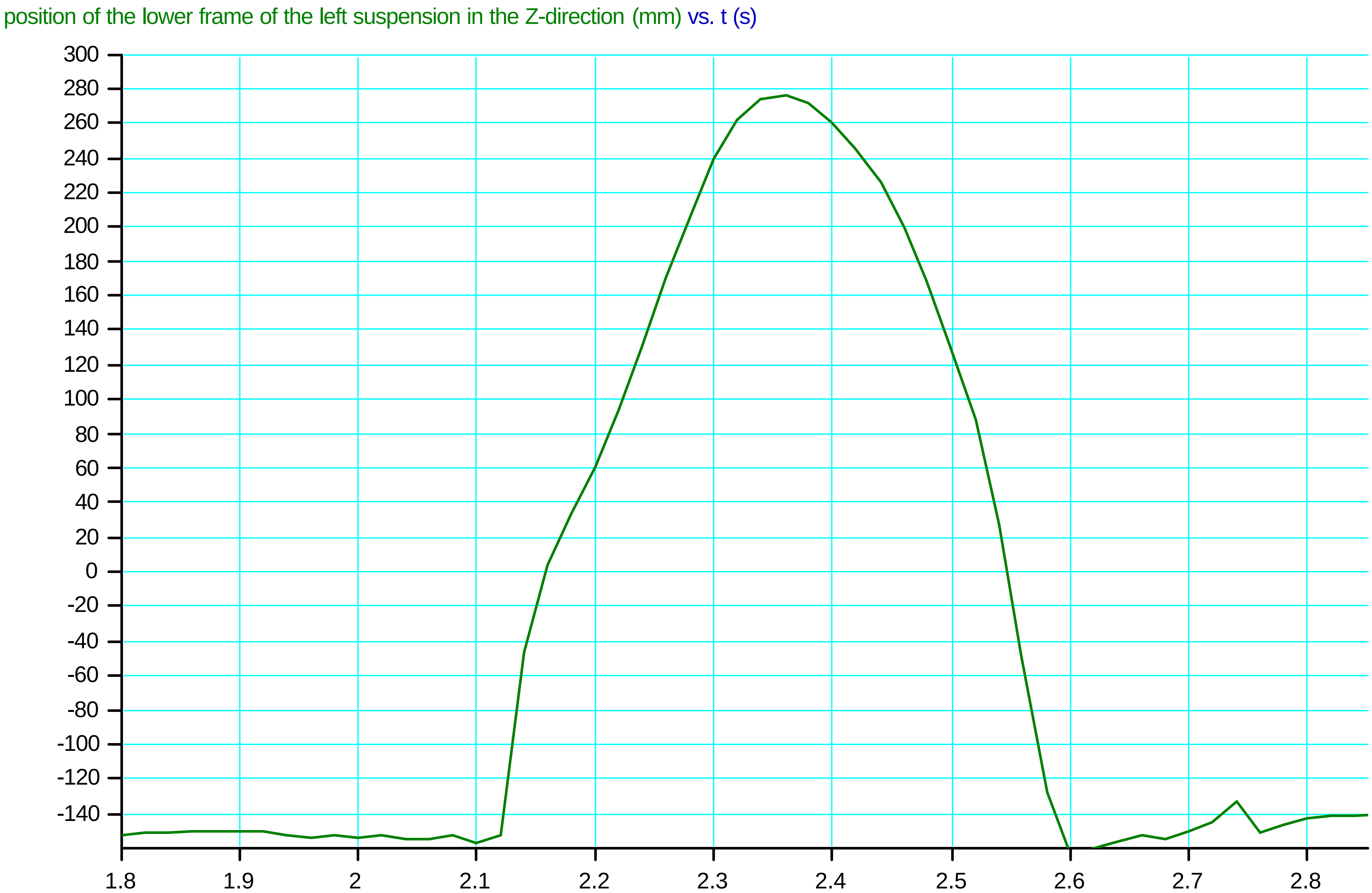
Simulation settings:

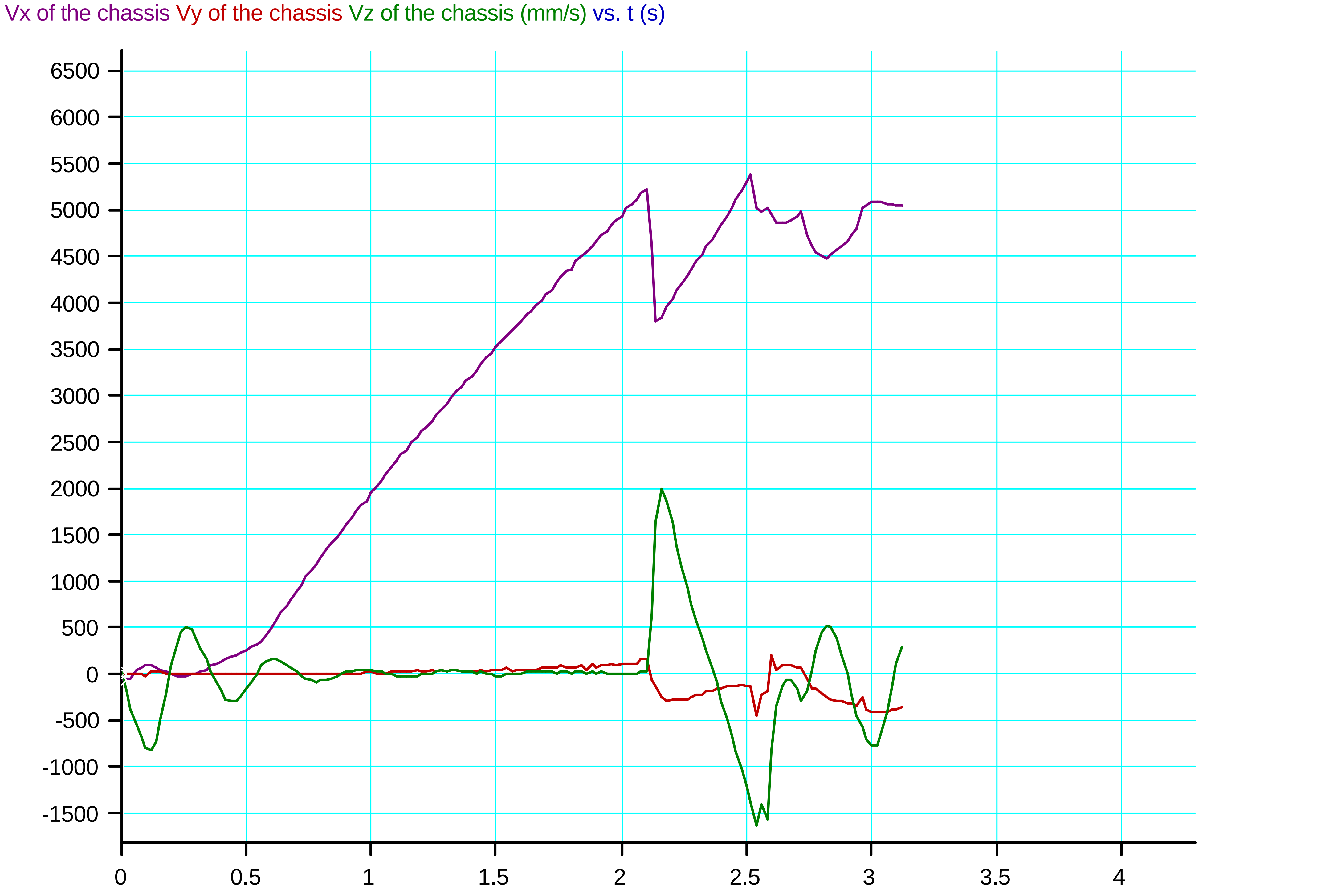
Front spring stiffness (k): 80 KN/m
Front spring damping coefficient (c): 1700 kg/s
Natural front spring length: 0.26 m
Rear spring stiffness (k): 60 KN/m
Rear damping coefficient (C): 500 kg/s
Natural rear spring length: 0.48 m
Deriving force: an applied force to the center of the rear mid beam of the chassis, acting in the x-direction, the initial force is 160 N and continue to rise until it reach 4000 N.
***Note: (the force magnitude is controlled during the simulation by an input controller slider).**
The chassis mass: 98 kg.
The rear box (represent the motor) mass: 200 kg.
The mid box represents the passenger and other car accessories mass: 500 kg.
Wheels coefficient of friction: 0.5
Wheels coefficient of restitution: 0.5
Rear wheel mass: 15 kg
Front wheel mass: 10 kg
Rear wheel dimensions: (diameter: 0.5 m) (height: 0.15m)
Front wheel dimensions: (diameter: 0.45 m) (height: 0.125 m).
Road pump height: 0.17 m
Road pump length: 0.6 m

Data analysis:

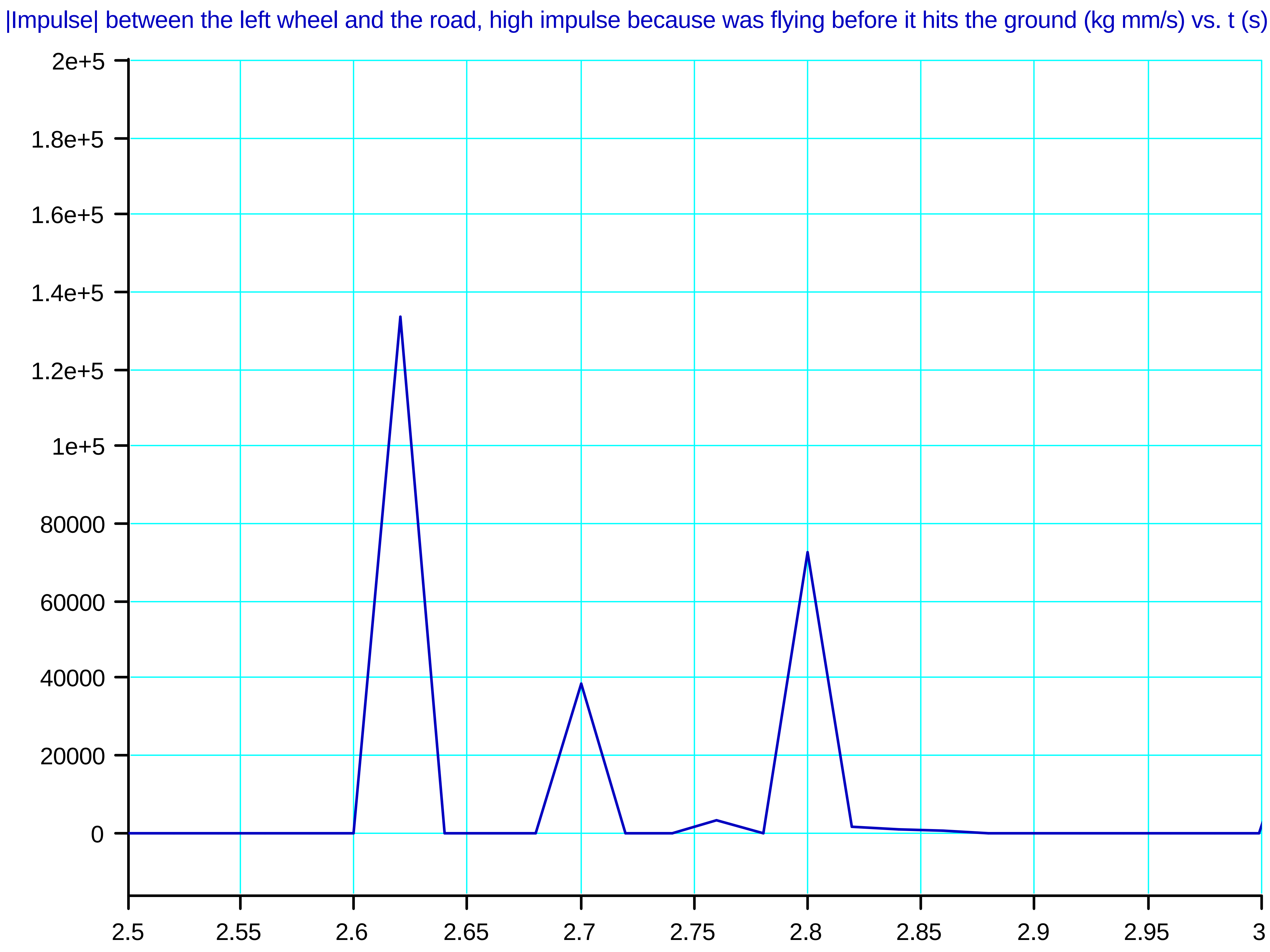
From the movie it could be seen that the car lose control when it hits the pump. The reason maybe that deriving force acts as a coupling force with the reaction force from the right wheel, which hit the pump first.
***Note: the average velocity of the car when passing over the pump is (21 km/h), which is relatively high speed for a car over a pump.**


position of the chassis in the Z-sirection. (mm) vs. t (s)
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3


position of the lower frame of the left suspension in the Z-direction (mm) vs. t (s)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8

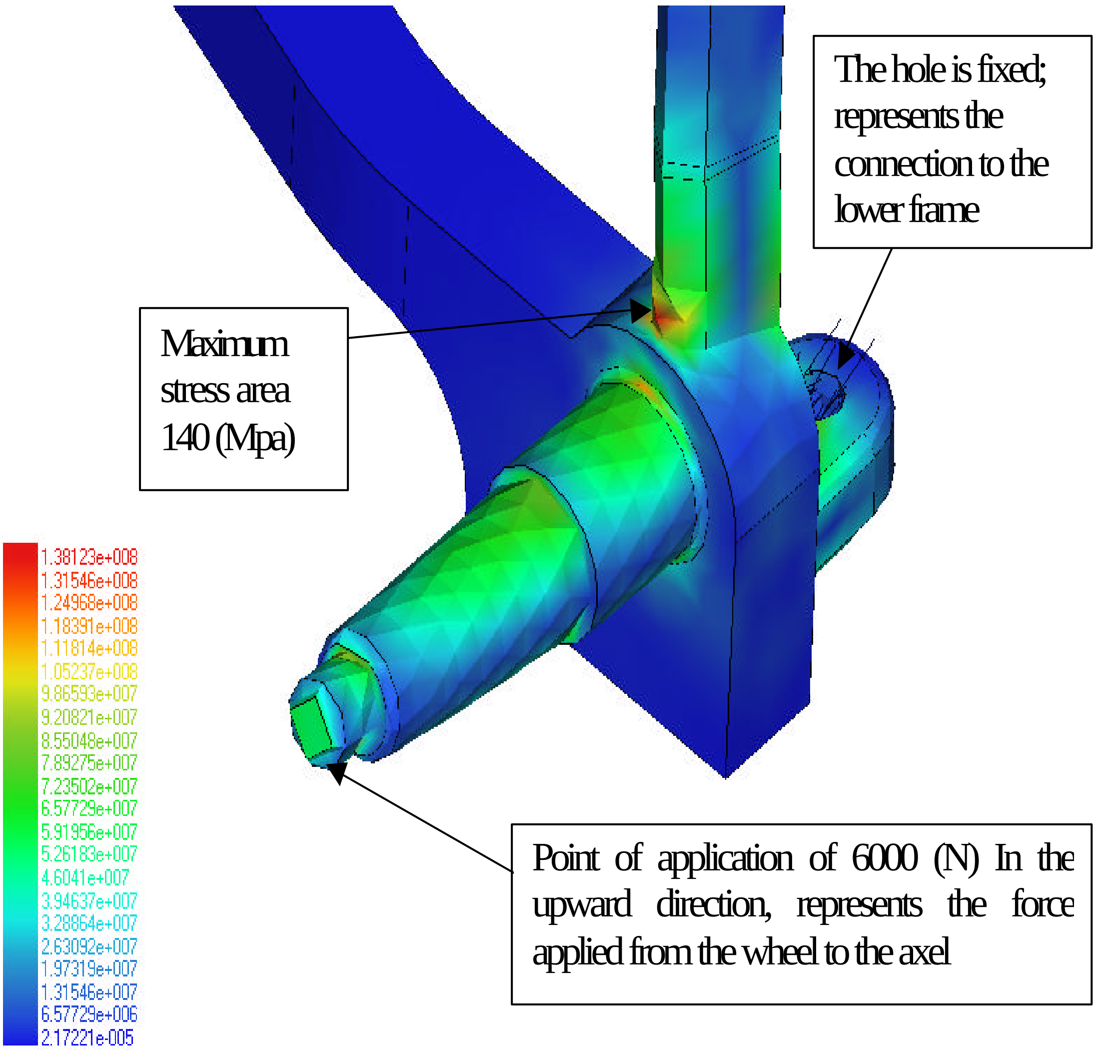


Vx of the chassis Vy of the chassis Vz of the chassis (mm/s) vs. t (s)
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
0
0.5
1
1.5
2
2.5
3
3.5
4


|Impulse| between the left wheel and the road, high impulse because was flying before it hits the ground (kg mm/s) vs. t (s)
2e+5
1.8e+5
1.6e+5
1.4e+5
1.2e+5
1e+5
80000
60000
40000
20000
0
2.5
2.55
2.6
2.65
2.7
2.75
2.8
2.85
2.9
2.95
3

Stress analysis for the front axel.

After solid modeling the axel in the mechanical desktop software, I used working model (FEA) for MDT to perform analytical stress calculation for the axel.



The maximum applied stress on this part is 140 Mpa while the maximum yield strength is 331 Mpa. So the factor of safety for this part is (2.4).
The following pages gives a detailed results about the computed stresses and reaction forces, and the material property of the axel.

F.E.A for the front left axel

Model Summary

Client: Graduation project
Engineer: Husam Barham
Company: J.U.S.T
Part Name: axel104
Simulation Program: Working Model FEA for Mechanical Desktop
Model Name: axel103_Model
Result Case 1: axel103_ModelStress

Engineer's notes: the forces applied to the axel is due to the static loading of the car with a load factor of saftey

axel103_ModelStress Summary

PARAMETER	VALUE	COMMENTS
Stress	2.17221e-005 N/m**2	Minimum Value - Global Cartesian Averaged Von Mises
Stress	1.38123e+008 N/m**2	Maximum Value - Global Cartesian Averaged Von
Applied Force	8.11239e-013 N	Minimum Value - Global Cartesian Magnitude
Applied Force	2.00000e+003 N	Maximum Value - Global Cartesian Magnitude
Reaction Force	2.55576e+001 N	Minimum Value - Global Cartesian Magnitude
Reaction Force	3.49930e+003 N	Maximum Value - Global Cartesian Magnitude
Displacement	1.28239e-006 m	Minimum Value - Global Cartesian Magnitude
Displacement	4.60521e-004 m	Maximum Value - Global Cartesian Magnitude

axel103_Model

PARAMETER	VALUE	COMMENTS
Number of Nodes:	4088	Number of nodes used for the model mesh.
Number of	2132	Number of elements used for the model mesh.

axel103_LS

TYPE	VALUE	CSYS	CSYS TYPE
Face Force:	6000.000000 [0.000000X, -6000.000000Y, 0.000000Z]	Global	Cartesian

axel103_RS

TYPE	VALUE	CSYS	CSYS TYPE
Face	[X][Z]	Global	Cartesian
Face	[Y][Z]	Global	Cartesian

Material Data - Steel - ANSI C1020

PARAMETER	VALUE @ 298.150000
Young's Modulus	1.99928e+011 N/m**2
Poisson's Ratio	2.90000e-001
Shear Modulus	7.74915e+010 N/m**2
Mass Density	7.85000e+003 Kg/m**3
Thermal Coefficient of	1.13073e-005 m/m/degK
Allowable Stress	4.48137e+008 N/m**2
Maximum Yield Stress	3.30932e+008 N/m**2
Thermal Conductivity	4.67400e+001 J/sec*m*degK

Specific Heat	4.18400e+002 J/Kg*degK

axel103_ModelStress - Details (All values are averaged and in the global cartesian coordinate system)

PARAMETER	X VALUE	Y VALUE	Z VALUE
Location	9.50000e-003 m	7.10543e-017 m	-1.60000e-001 m
Applied Force	0.00000e+000 N	-1.32015e-012 N	0.00000e+000 N
Location	4.75000e-003 m	-4.75000e-003 m	-1.60000e-001 m
Applied Force	0.00000e+000 N	-1.00016e+003 N	0.00000e+000 N
Location	-2.38761e-009 m	-9.50000e-003 m	-1.60000e-001 m
Applied Force	0.00000e+000 N	-8.11239e-013 N	0.00000e+000 N
Location	-4.75000e-003 m	-4.74851e-003 m	-1.60000e-001 m
Applied Force	0.00000e+000 N	-1.00016e+003 N	0.00000e+000 N
Location	-9.50000e-003 m	2.98690e-006 m	-1.60000e-001 m
Applied Force	0.00000e+000 N	-1.69806e-012 N	0.00000e+000 N
Location	-4.74701e-003 m	4.75149e-003 m	-1.60000e-001 m
Applied Force	0.00000e+000 N	-9.99843e+002 N	0.00000e+000 N
Location	5.97141e-006 m	9.50000e-003 m	-1.60000e-001 m
Applied Force	0.00000e+000 N	-8.76743e-013 N	0.00000e+000 N
Location	4.75299e-003 m	4.75000e-003 m	-1.60000e-001 m
Applied Force	0.00000e+000 N	-9.99843e+002 N	0.00000e+000 N
Location	2.34778e-010 m	1.49345e-006 m	-1.60000e-001 m
Applied Force	0.00000e+000 N	-2.00000e+003 N	0.00000e+000 N

axel103_ModelStress Summations

PARAMETER	X VALUE	Y VALUE	Z VALUE
Summation of Reaction Forces	-1.75476e-003 N	6.00002e+003 N	3.47090e-003 N
Summation of Reaction	1.76022e+003 N*m	6.30627e-002 N*m	-1.45127e+000 N*m

Steering system (An overview).

You know that when you turn the steering wheel in your car, the wheels turn. Cause and effect, right? However, a lot of interesting stuff goes on between the steering wheel and the tires to make this happen. Here are some facts.

Turning the Car.

For a car to turn smoothly, each wheel must follow a different circle. Since the inside wheel is following a circle with a smaller radius, it is actually making a tighter turn than the outside wheel. If you draw a line perpendicular to each wheel, the lines will intersect at the center point of the turn. The geometry of the steering linkage makes the inside wheel turn more than the outside wheel.

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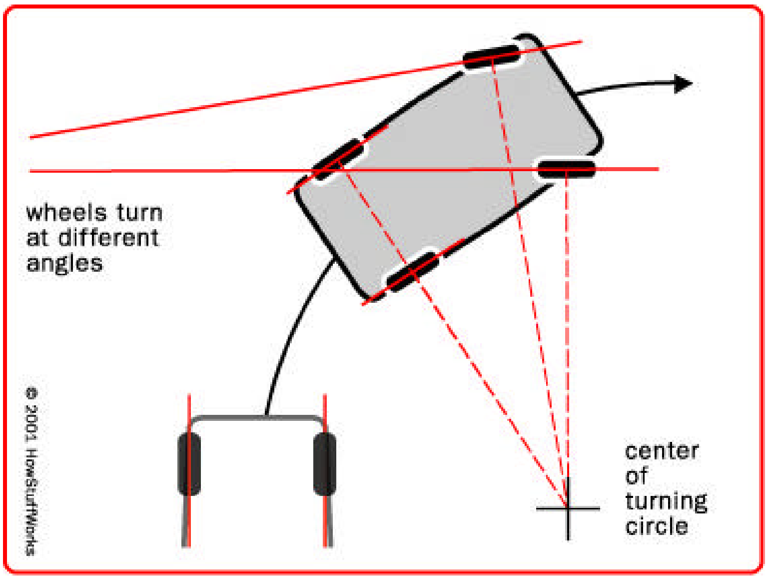


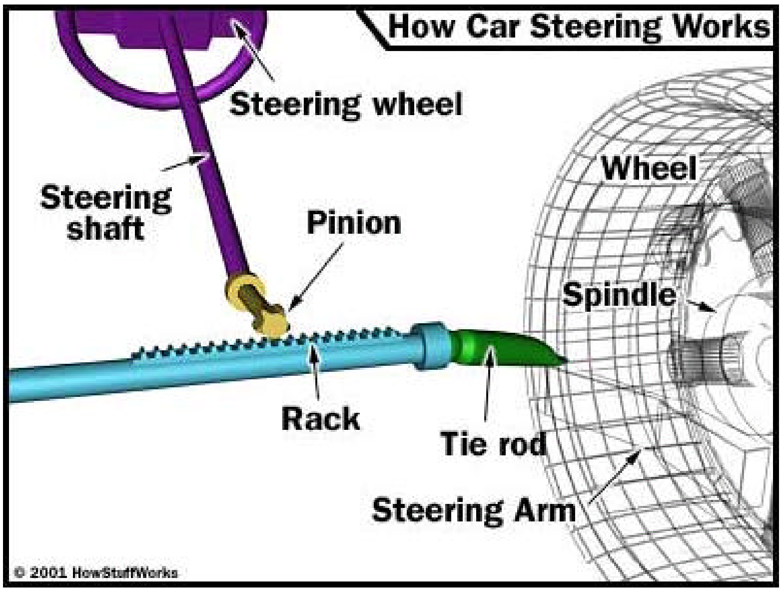
Steering system main parts and types.

Two of the most common steering mechanisms are the "rack and pinion" and the standard (or recirculating-ball) systems, that can be either manual or assisted by power. The rack and pinion was designed for sports cars and requires too much driver muscle at low speeds to be very useful in larger, heavier cars. However, power steering makes a heavy car respond easily to the steering wheel, whether at highway speeds or inching into a narrow parking place, and it is normal equipment for large automobiles. A brief description about each mechanism is presented next.

Rack-and-pinion Steering.

Rack-and-pinion steering is quickly becoming the most common type of steering on cars, small trucks and SUVs. It is actually a pretty simple mechanism.

A rack-and-pinion gear set is enclosed in a metal tube, with each end of the rack protruding from the tube. A rod, called a tie rod, connects to each end of the rack.



The pinion gear is attached to the steering shaft. When you turn the steering wheel, the gear spins, moving the rack. The tie rod at each end of the rack connects to the steering arm on the spindle (see diagram above).

The rack-and-pinion gearset does two things:

- It converts the rotational motion of the steering wheel into the linear motion needed to turn the wheels.
- It provides a gear reduction, making it easier to turn the wheels.

On most cars, it takes three to four complete revolutions of the steering wheel to make the wheels turn from lock to lock (from far left to far right).

The steering ratio is the ratio of how far you turn the steering wheel to how far the wheels turn. For instance, if one complete revolution (360 degrees) of the steering wheel results in the wheels of the car turning 20 degrees, then the steering ratio is 360 divided by 20, or 18:1. A higher ratio means that you have to turn the steering wheel more to get the wheels to turn a given distance. However, less effort is required because of the higher gear ratio.

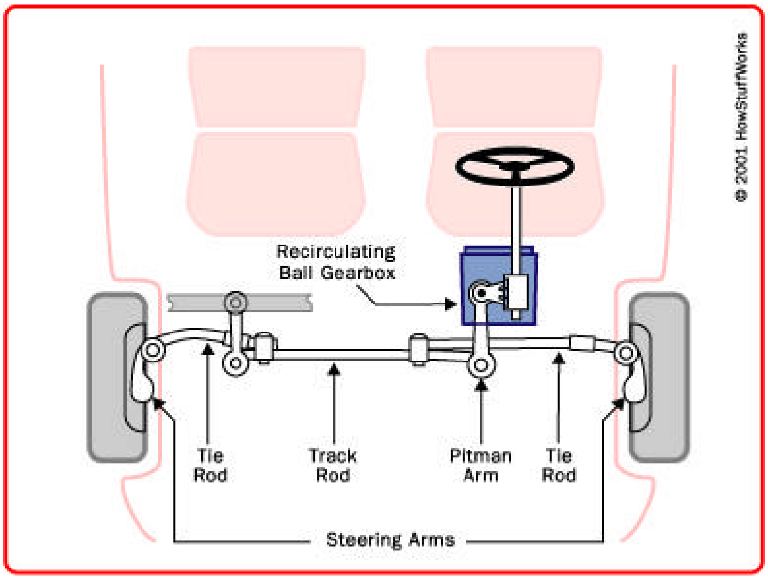
Generally, lighter, sportier cars have lower steering ratios than larger cars and trucks. The lower ratio gives the steering a quicker response -- you don't have to turn the steering wheel as much to get the wheels to turn a given distance -- which is a desirable quality in sports cars. These smaller cars are light enough that even with the lower ratio, the effort required to turn the steering wheel is not excessive. Due to the light weight of the buggy off-road car and to the rapid reactions in varying the direction, it has been taken in consideration to have a lower steering ratio during the design process.

Some cars have variable-ratio steering, which uses a rack-and-pinion gearset that has a different tooth pitch in the center than it has on the outside. This makes the car respond quickly when starting a turn (the rack is near the center), and also reduces effort near the wheel's turning limits.

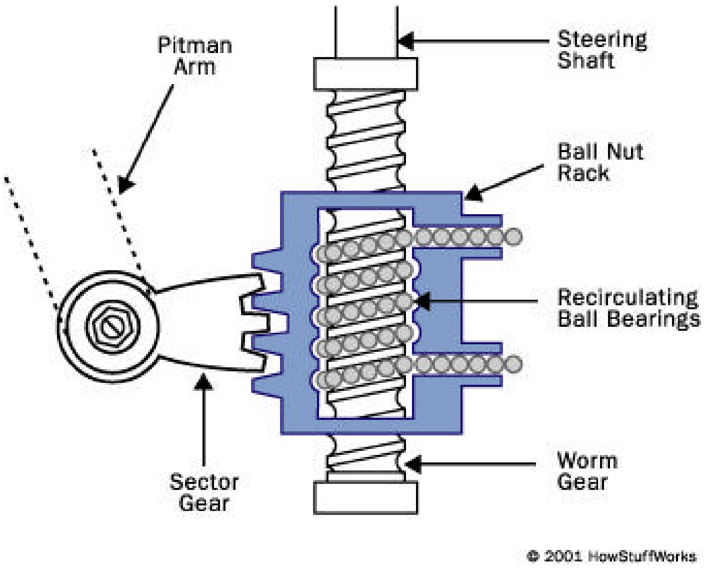
The advantage of rack & pinion steering is that it is more precise than the mechanical system. By reducing the number of parts and pivot points, it can more accurately control wheel direction and is more responsive. The down side of a rack & pinion steering system is that they are prone to leakage requiring replacement of the rack assembly.

Recirculating-ball Steering.

Recirculating-ball steering is used on mainly on trucks. The linkage that turns the wheels is slightly different than on a rack-and-pinion system.



The recirculating-ball steering gear contains a worm gear. You can image the gear in two parts. The first part is a block of metal with a threaded hole in it. This block has gear teeth cut into the outside of it, which engage a gear that moves the pitman arm (see diagram above). The steering wheel connects to a threaded rod, similar to a bolt, that sticks into the hole in the block. When the steering wheel turns, it turns the bolt. Instead of twisting further into the block the way a regular bolt would, this bolt is held fixed so that when it spins, it moves the block, which moves the gear that turns the wheels.



Instead of the bolt directly engaging the threads in the block, all of the threads are filled with ball bearings that recirculate through the gear as it turns. The balls actually serve two purposes: First, they reduce friction and wear in the gear; second, they reduce slop in the gear. Slop would be felt when you change the direction of the steering wheel -- without the balls in the steering gear, the teeth would come out of contact with each other for a moment, making the steering wheel feel loose.

Power steering in a recirculating-ball system works similarly to a rack-and-pinion system. Assist is provided by supplying higher-pressure fluid to one side of the block.

Steering system design

After taking in consideration the required performance from an off-road buggy car, such as the rapid change in directions and the factors affecting the steering system such as the light weight of the car and the rough road that an off-road car should pass through, I concluded that a rack and pinion steering mechanism should formulate the best performance for this car. For these reasons, I made my mind to design a rack and pinion steering mechanism for the car.

The design process went through two main divisions.

First, are the motion analysis and simulation processes, which are done with working model software. These simulations help me to visualize the motion type of the steering mechanism and the functionary of the system parts. Also, help me in providing the necessary dimensions for the parts and assembly, which is responsible on giving the best turning performance as, will be discussed later.

Second, are the C.A.D drawings; details, assemblies and the means of connections for the steering system parts. In this division a complete parts dimensions have been presented, which help visualize the steering system shape.

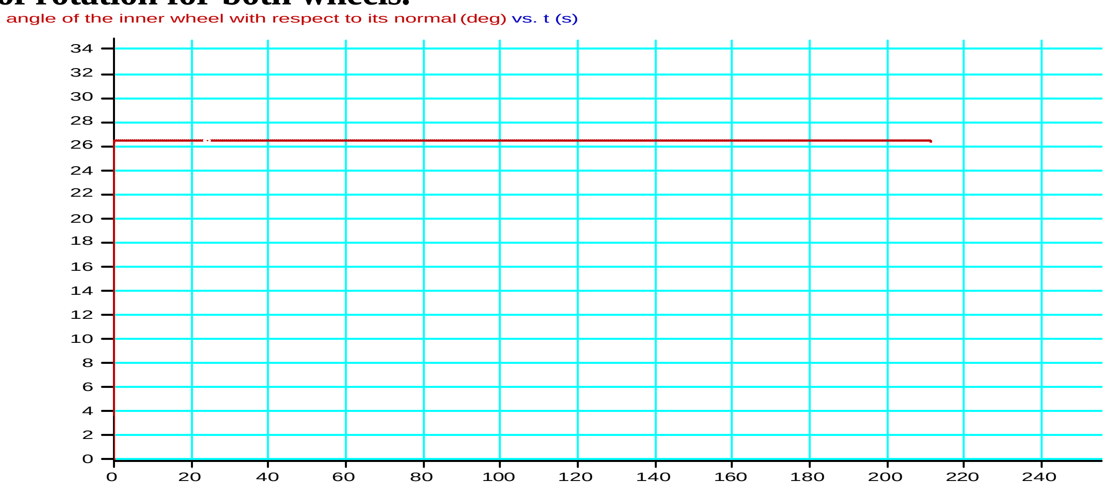
Simulation settings (initial settings)

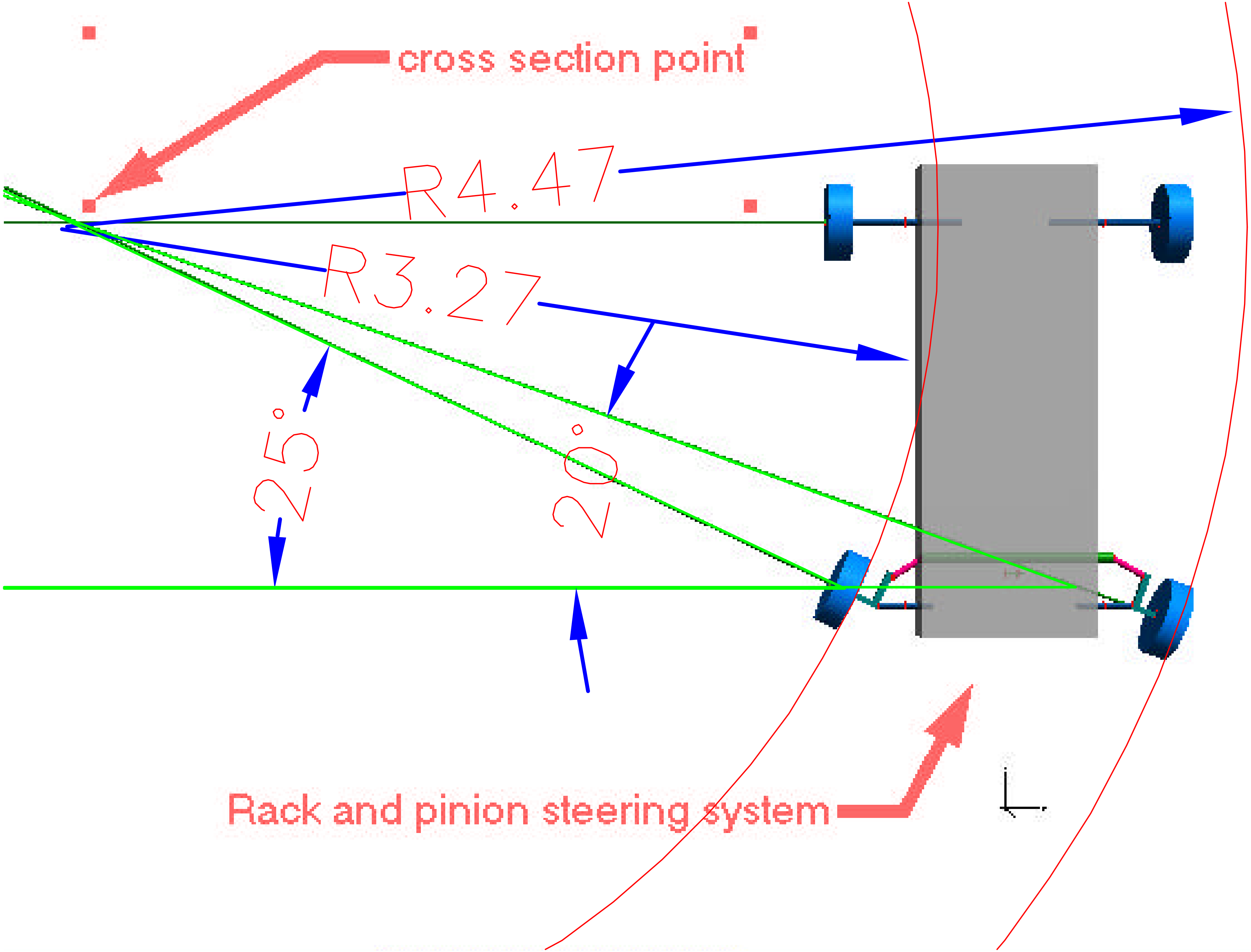
Rack length (cm): 120
Tie rod length (cm): 23
Axel arm (cm): 25
Axel spindle (cm): 18
Tire diameter (cm): 50
Car length (cm): 300
Car width (cm): 100
Car mass (kg): 650
Average velocity (m/s): 1 m/s
The rack position is: 8 cm to the right because of the assumed pinion rotation. This cause:-
The inner wheel to rotate to form an angle of 25 deg with its normal line
The outer wheel to rotate to form an angle of 21 deg with its normal line
Pinion diameter (cm): 9

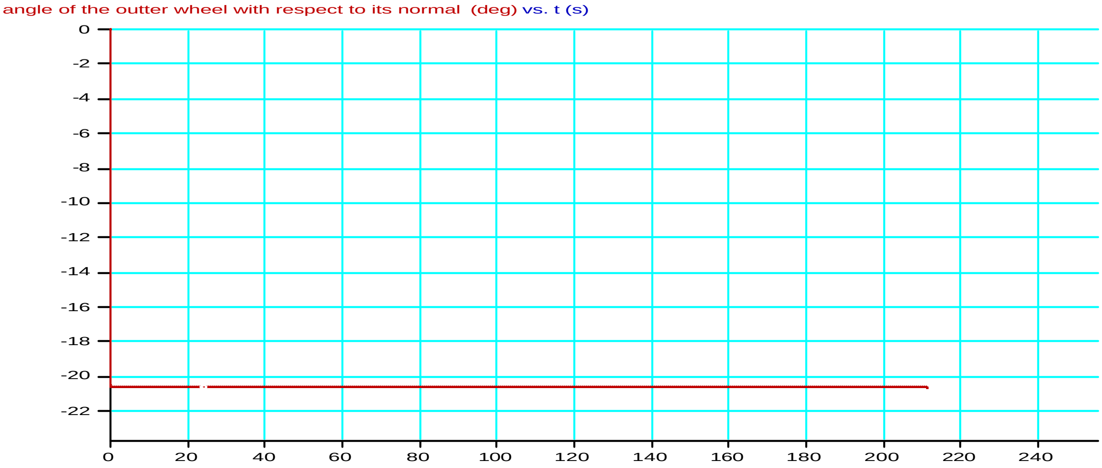
Simulation results (data analysis)

The given data will cause the three perpendicular lines on the right and left front wheels and on rear wheel, to intersect at one point(as shown in the figure next), which will be *the center of turning circle* for the car, this only happens when the rack shaft shifted 8 cm from its initial (center) position either to the left or to the right. This will also give the best turning performance, as the car will turn around it self on a complete circle path. The steering ratio is (360/25= 14.4) which is relatively good for a small car.

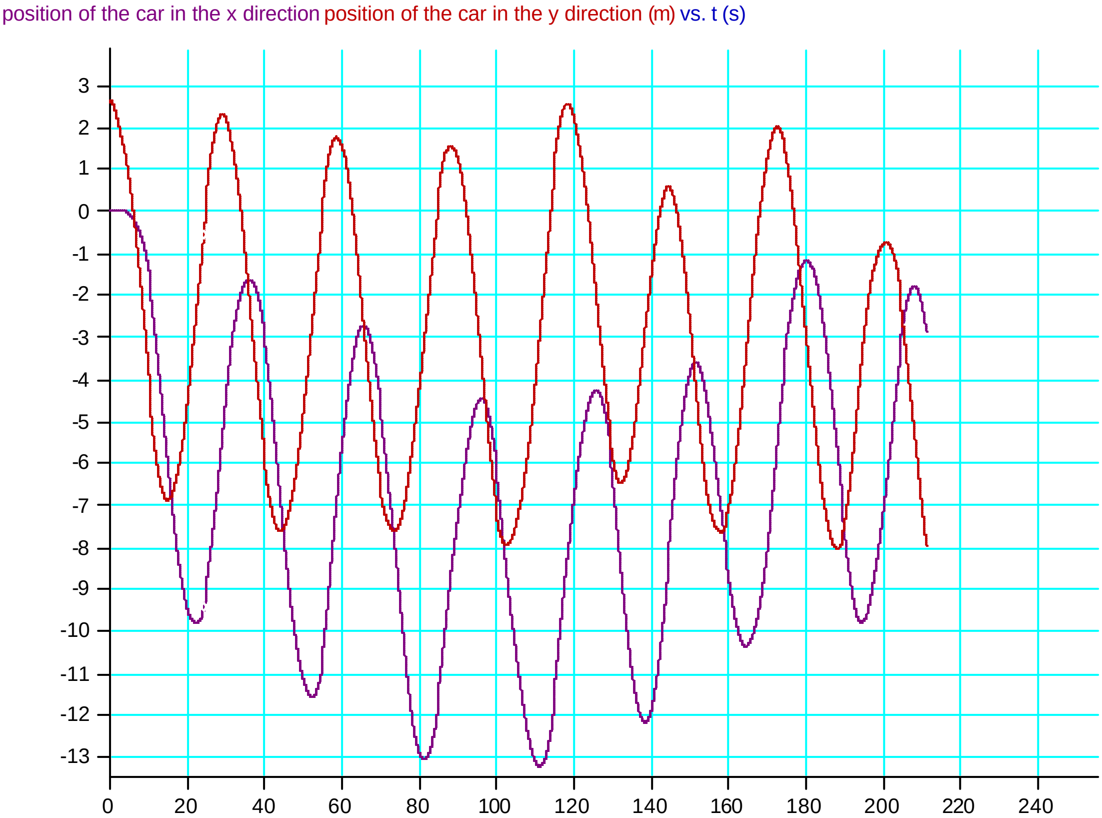
The following two charts show that angle of rotation for both front wheels were constant with time (notice the difference in the angle of rotation for both wheels.



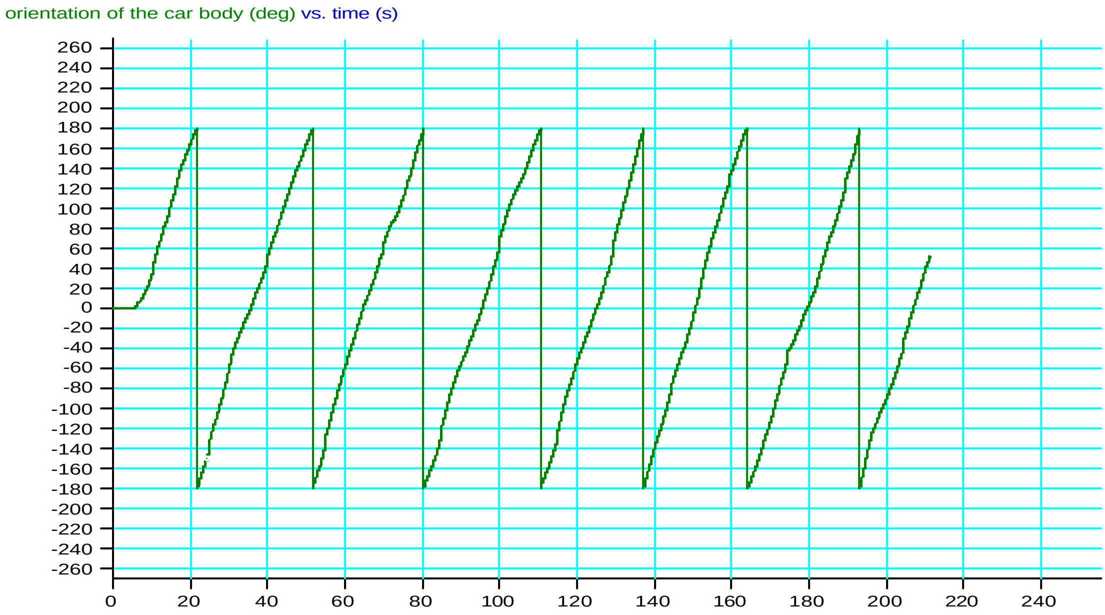

cross section point
R4.47
R3.27
25°
20°
Rack and pinion steering system



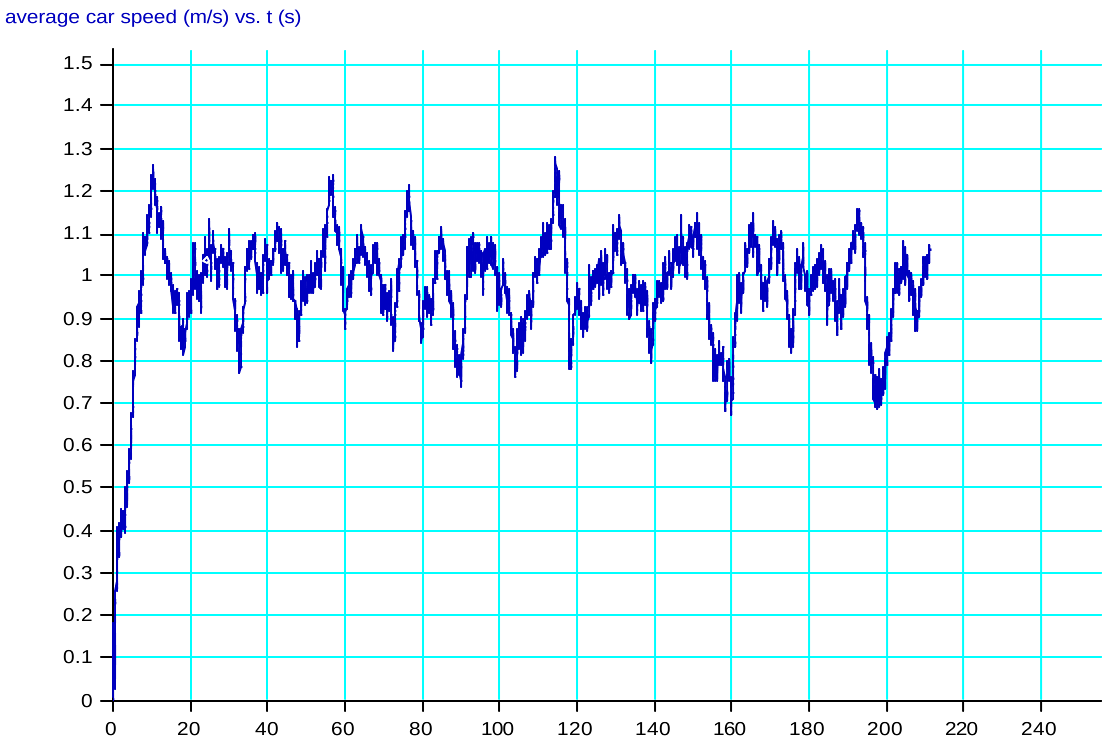
The next graph shows the position of the car in the x-y direction (considering the car move in the x-y plane). An important result giving here is that the car rotates around a circle of **(8 m)** average diameter as the variation between the maximum x-y positions and the minimum x-y positions relatively show. (Notice that the car rotates about (**7 turns**) around it self in this simulation as the sinusoidal wave show.



This chart shows the orientation of the car with respect to time. On an average basis, it took the car 25 second to have a complete 360-degree turn around its self. The car turns around it self 7 times in this simulation.

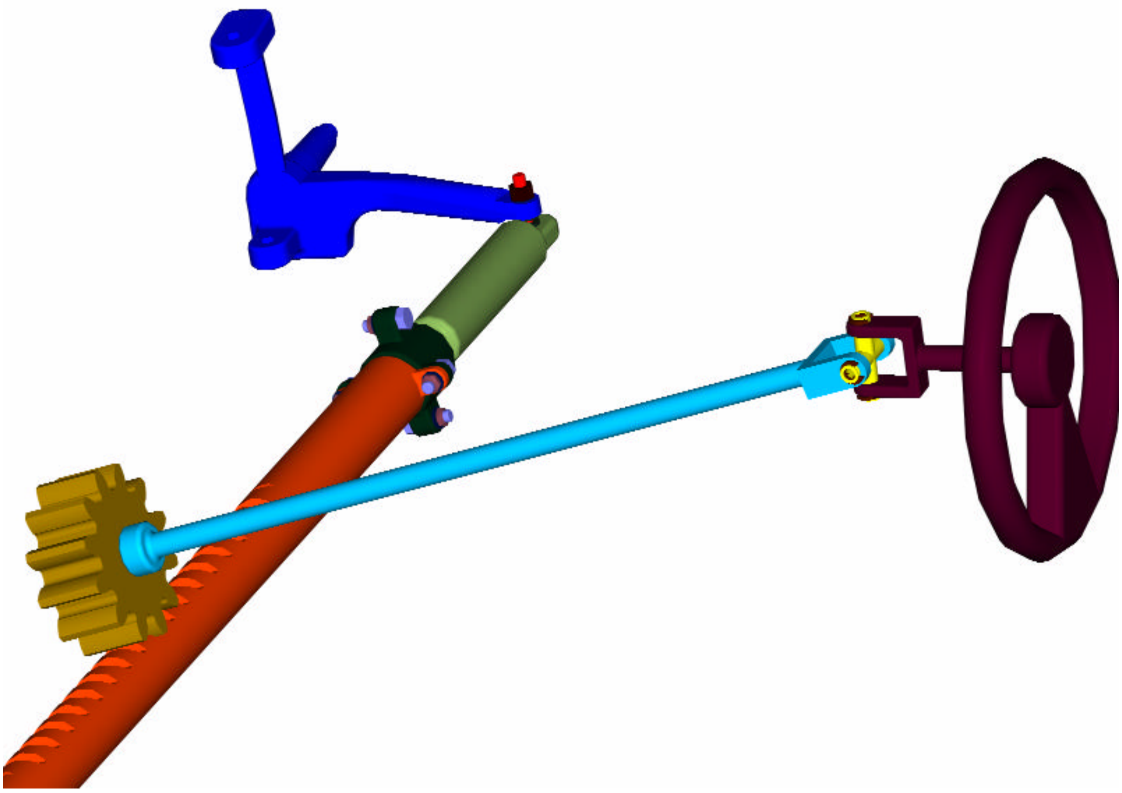


The car has an average speed of (1 m/s) as the chart below shows.

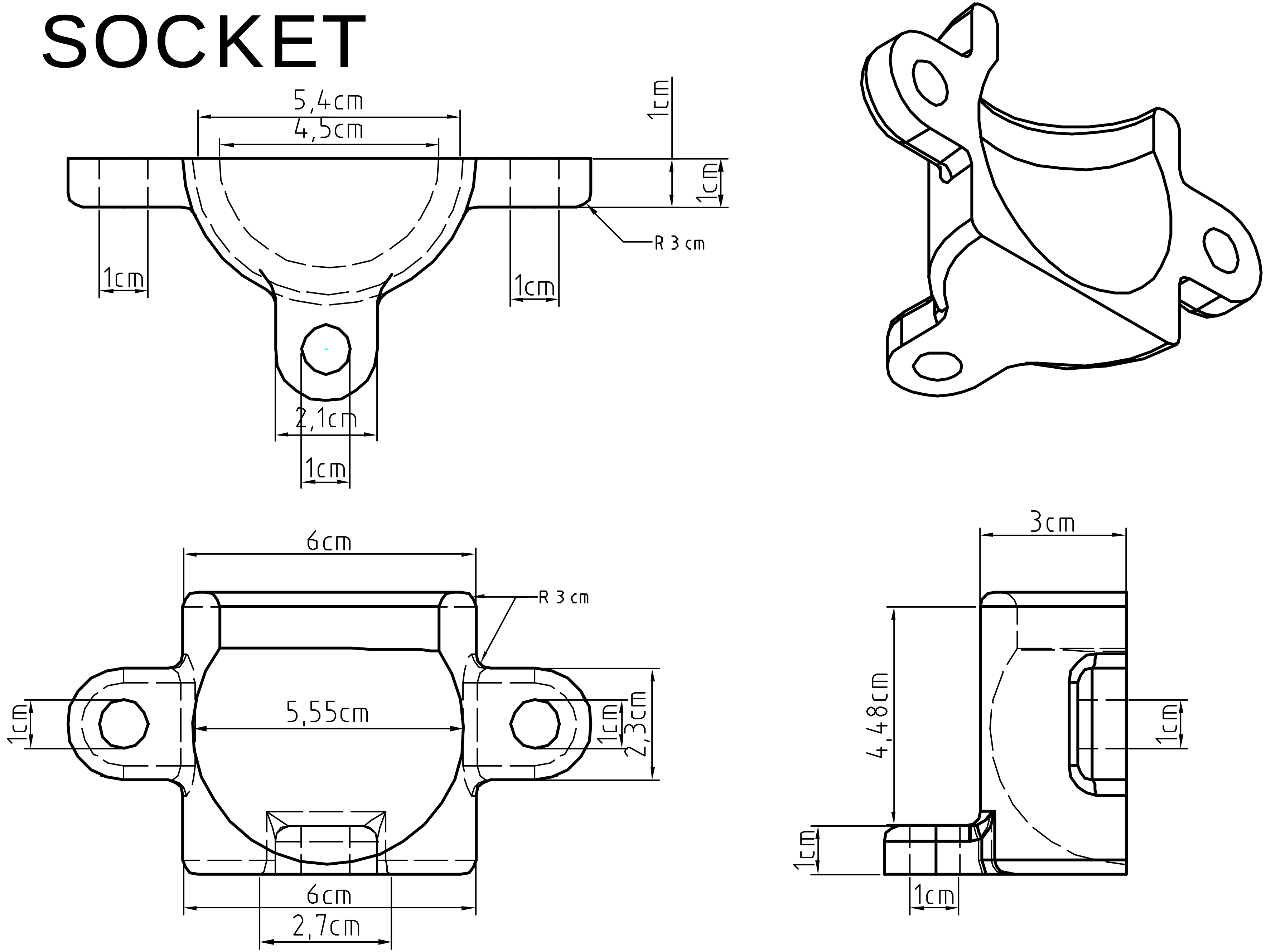


C.A.D DRAWINGS FOR THE RACK AND PINION STEERING SYSTEM

DETAILS
&
ASSEBLIES

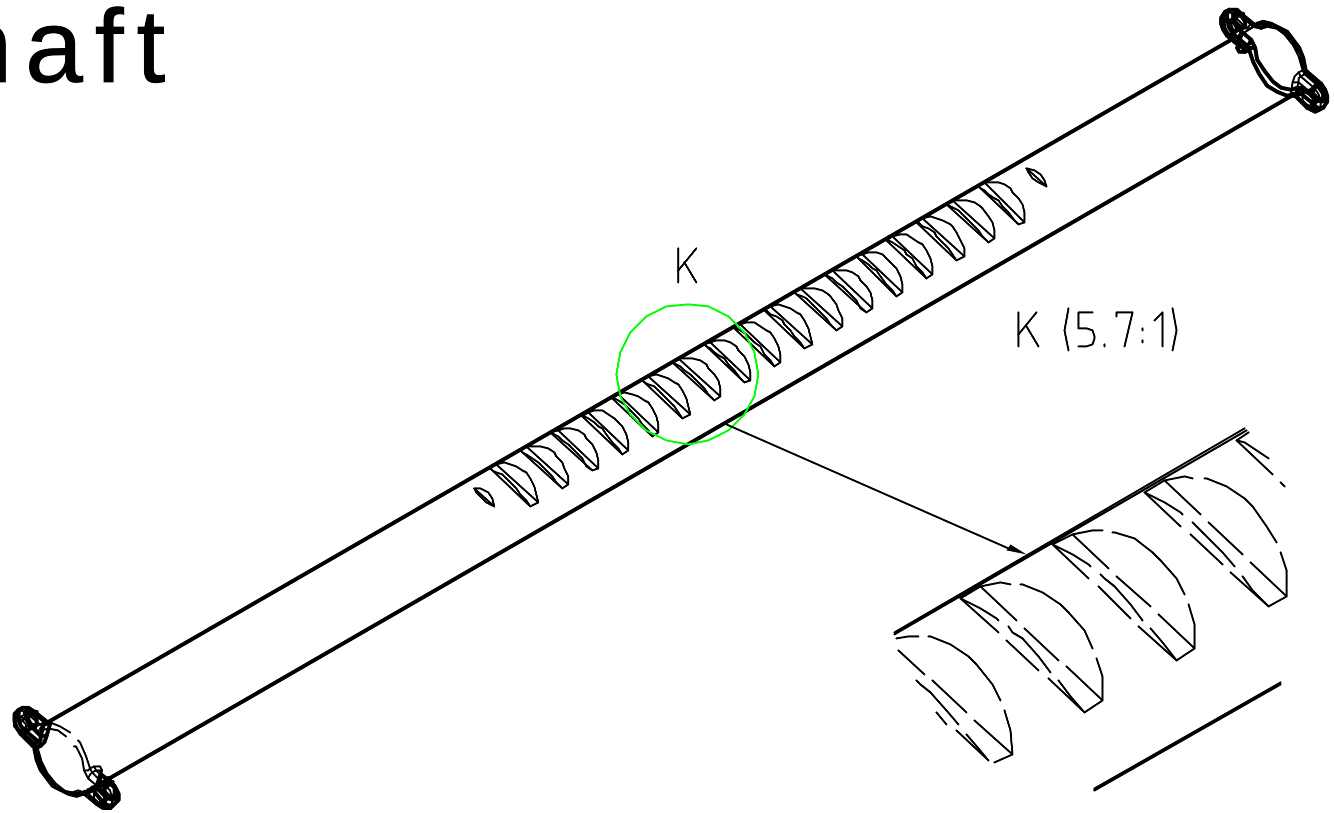


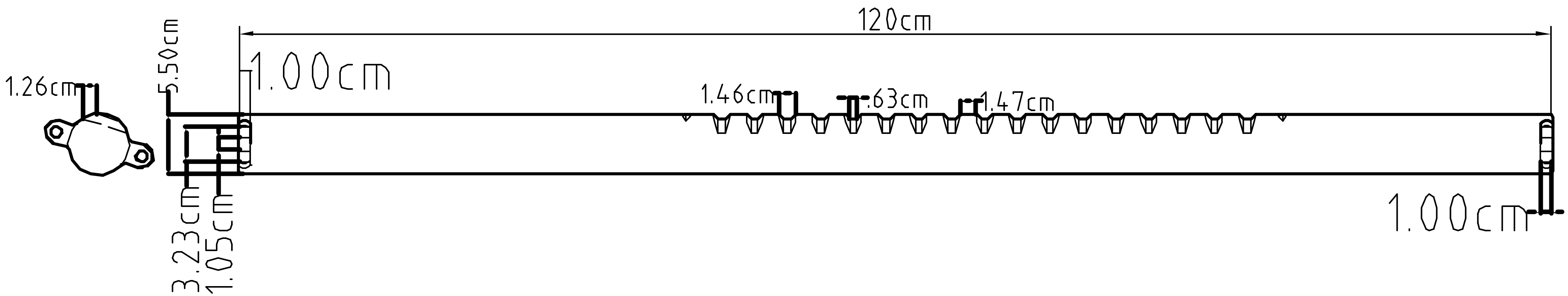
BALL SOCKET



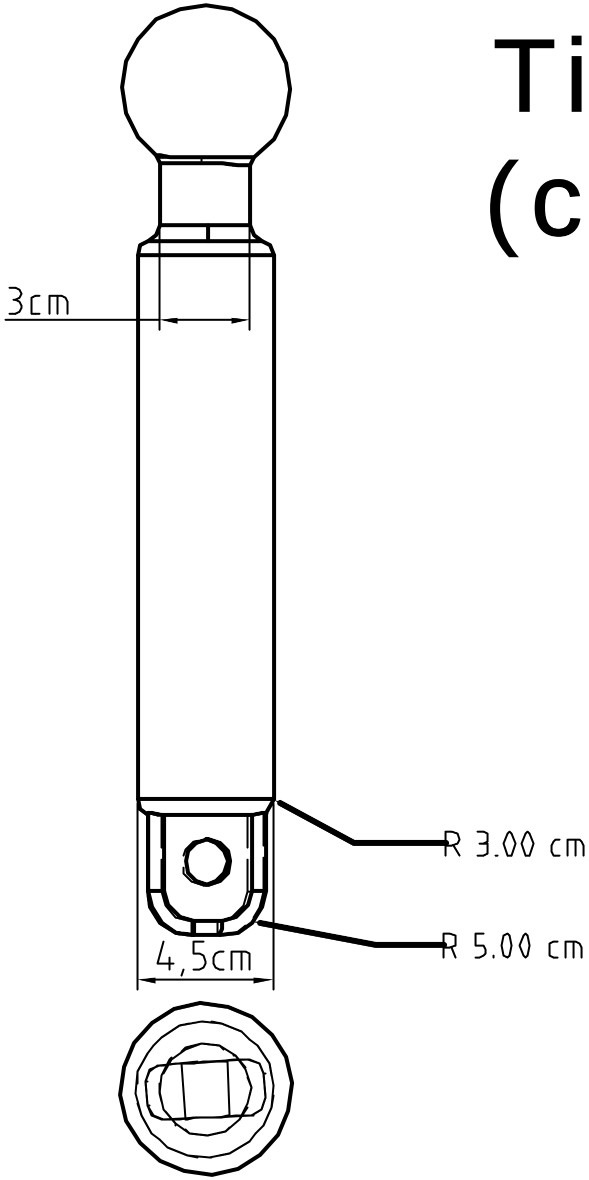
5,4cm
4,5cm
1cm
1cm
R 3cm
1cm
1cm
2,1cm
1cm
6cm
R 3cm
5,55cm
1cm
1cm
2,3cm
6cm
2,7cm
3cm
4,48cm
1cm
1cm
1cm

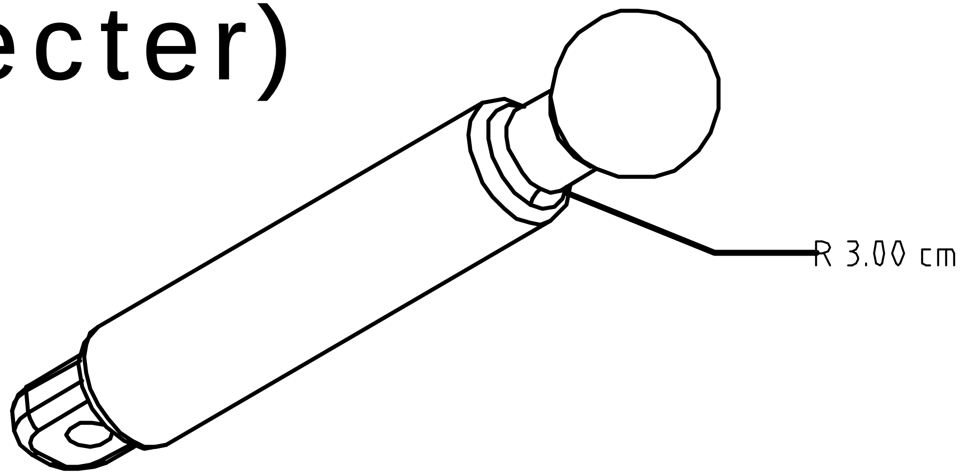
rack shaft

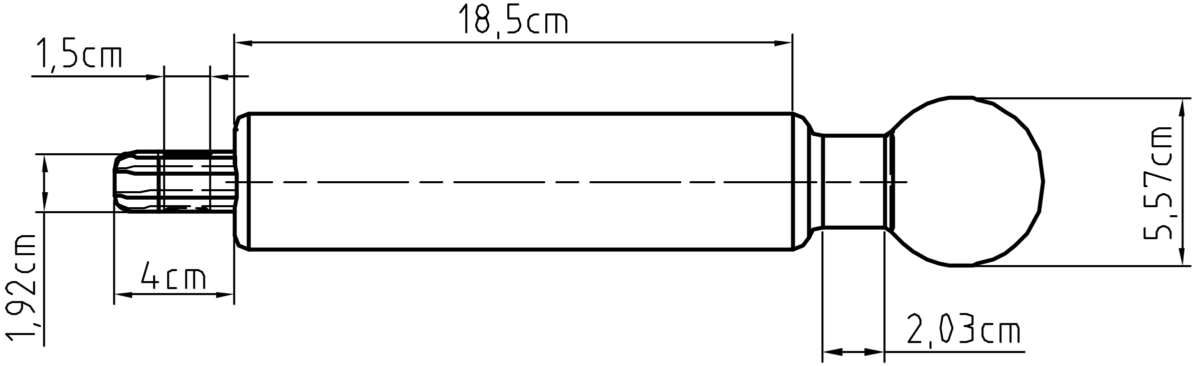

K
K (5.7:1)


120cm
1.00cm
1.26cm
5.50cm
1.46cm
.63cm
1.47cm
3.23cm
1.05cm
1.00cm

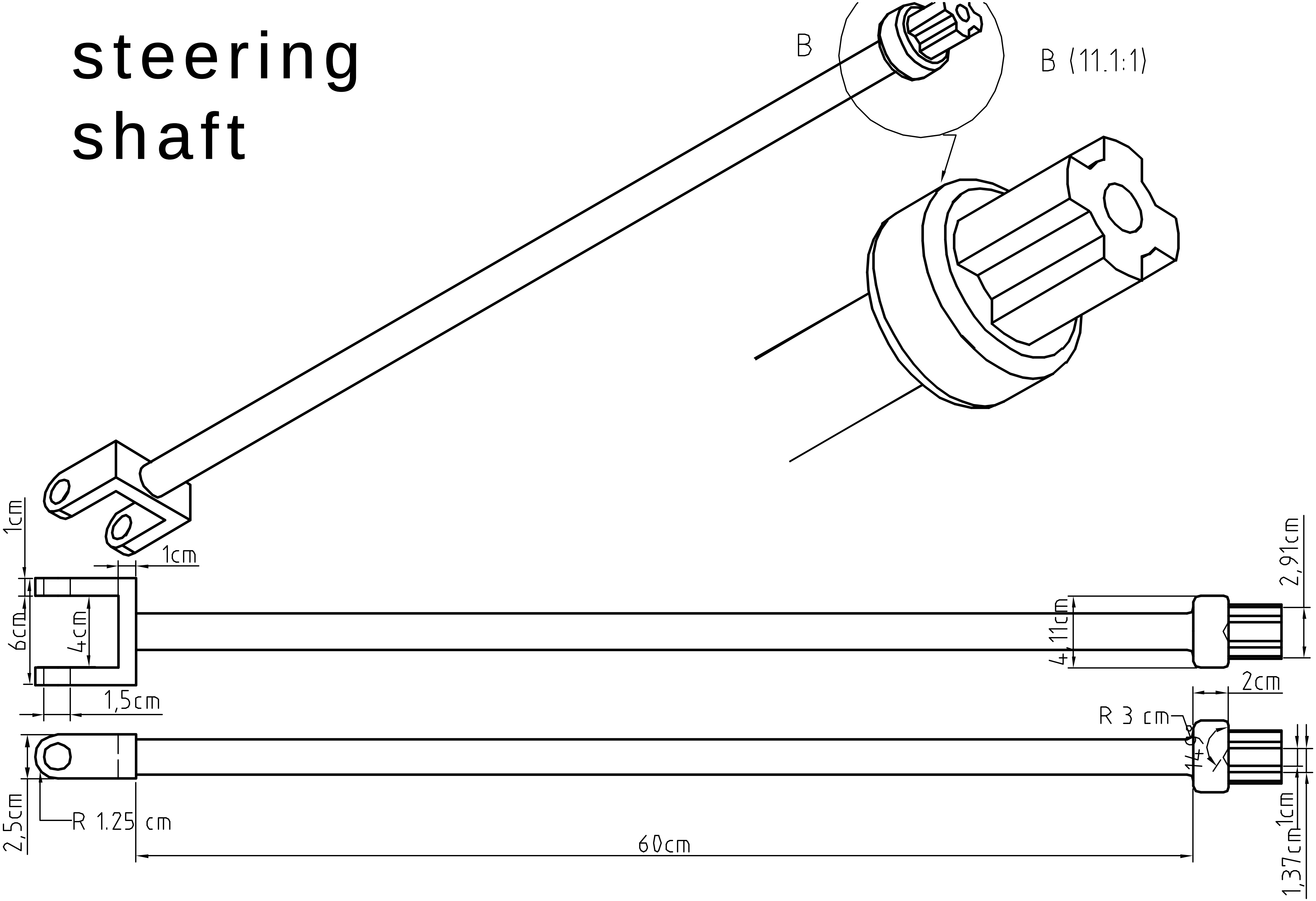
Tie rod (connecter)

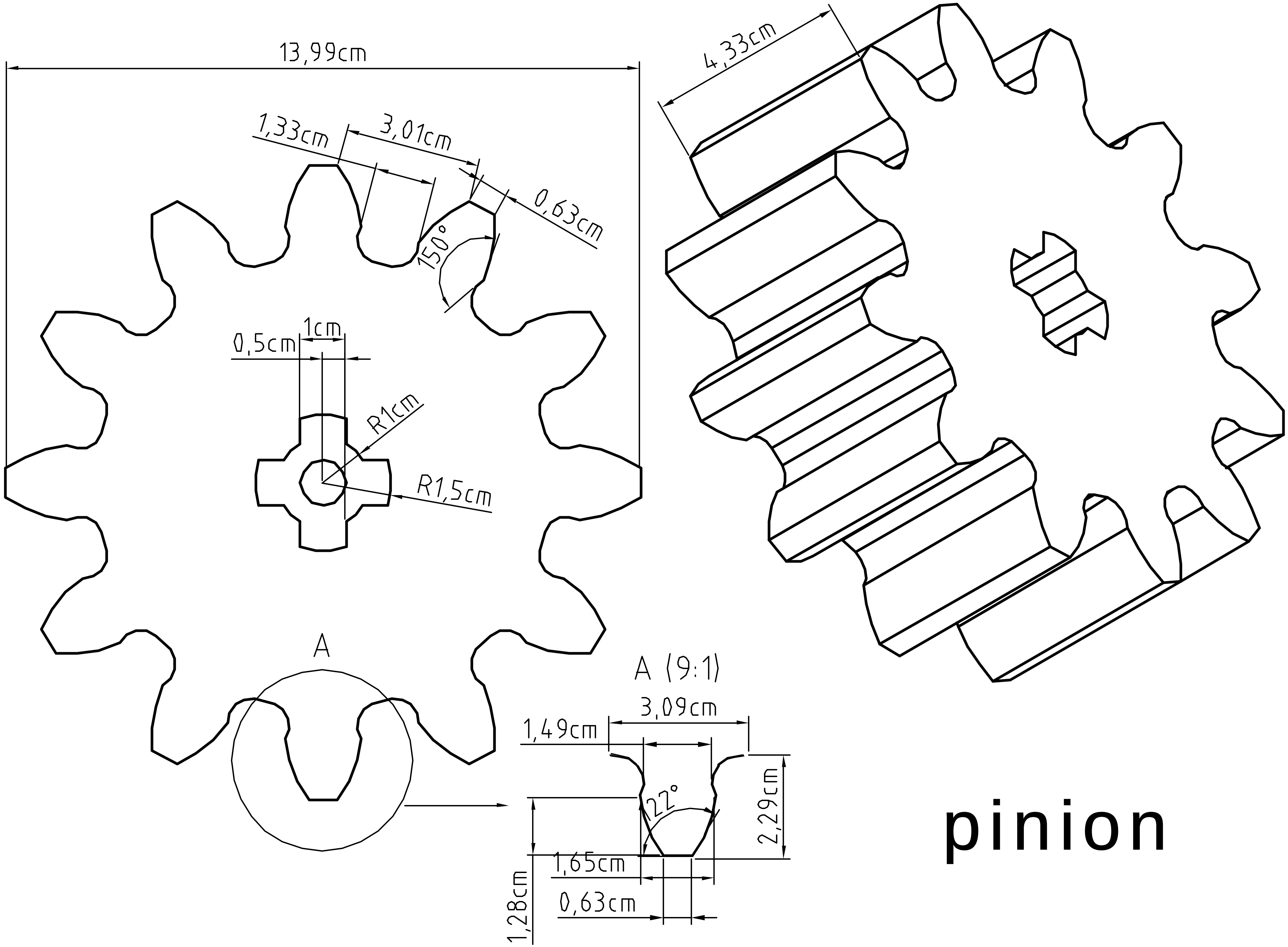




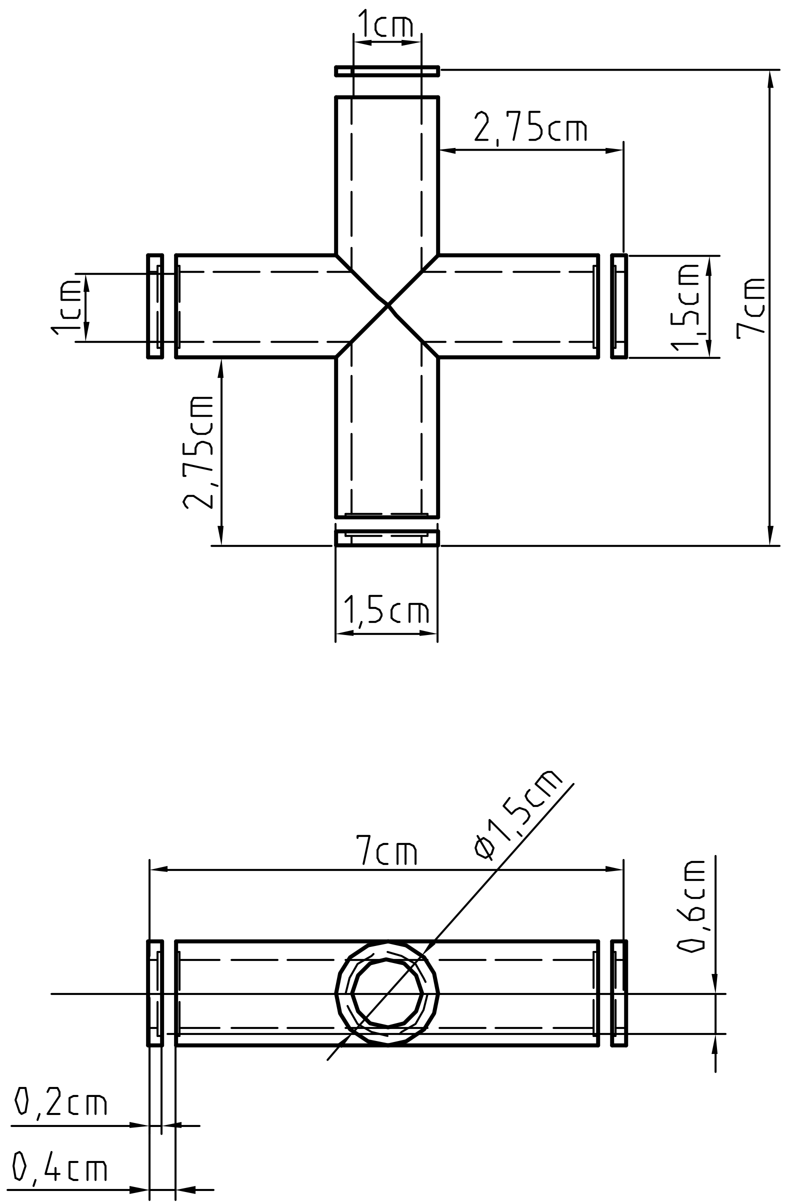


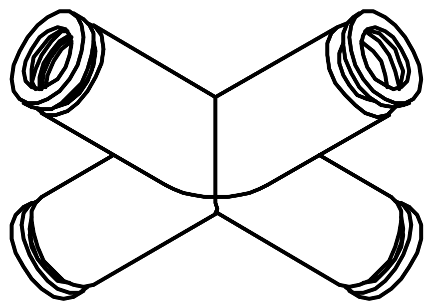
steering shaft




13,99cm
1,33cm
3,01cm
0,63cm
150°
1cm
0,5cm
R1cm
R1,5cm
A
4,33cm
A (9:1)
3,09cm
1,49cm
22°
2,29cm
1,65cm
1,28cm
0,63cm

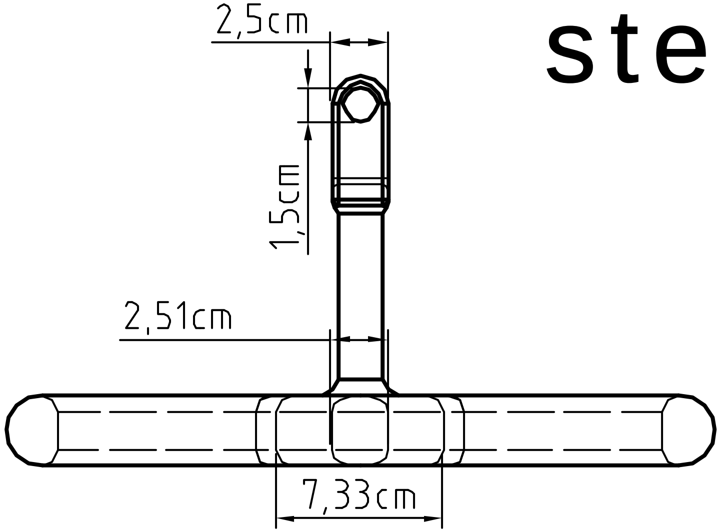
pinion



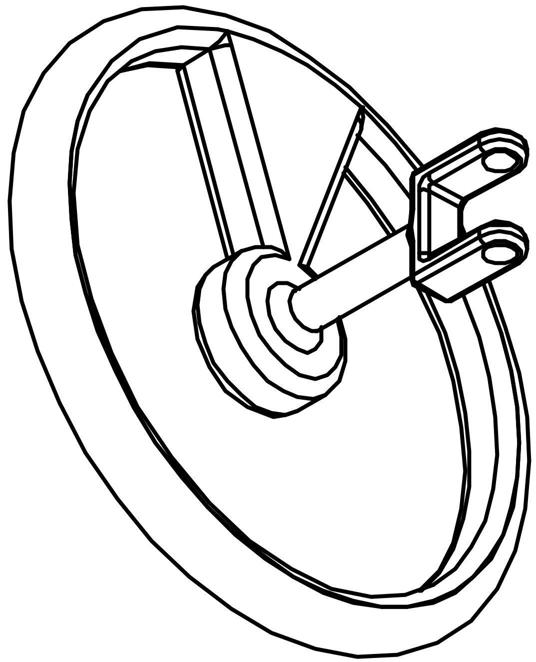


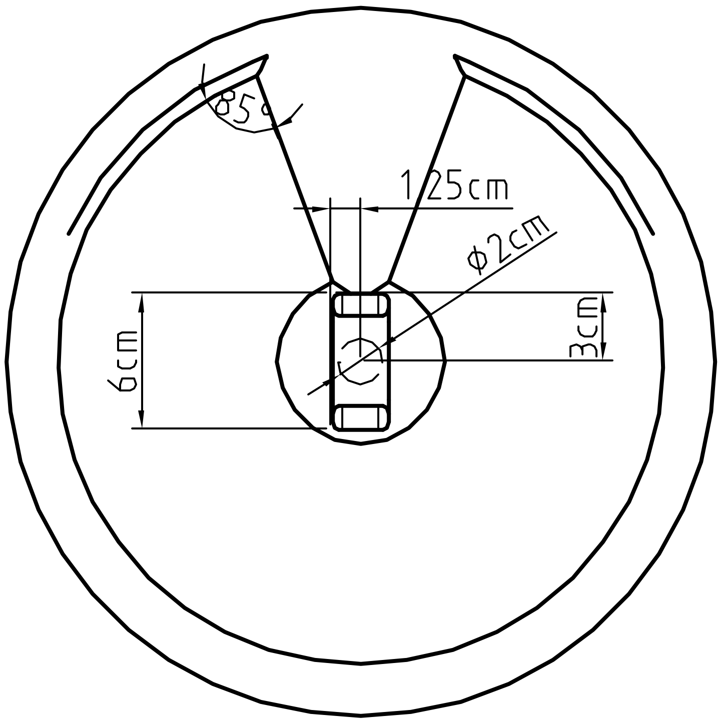
universal joint cross

steering

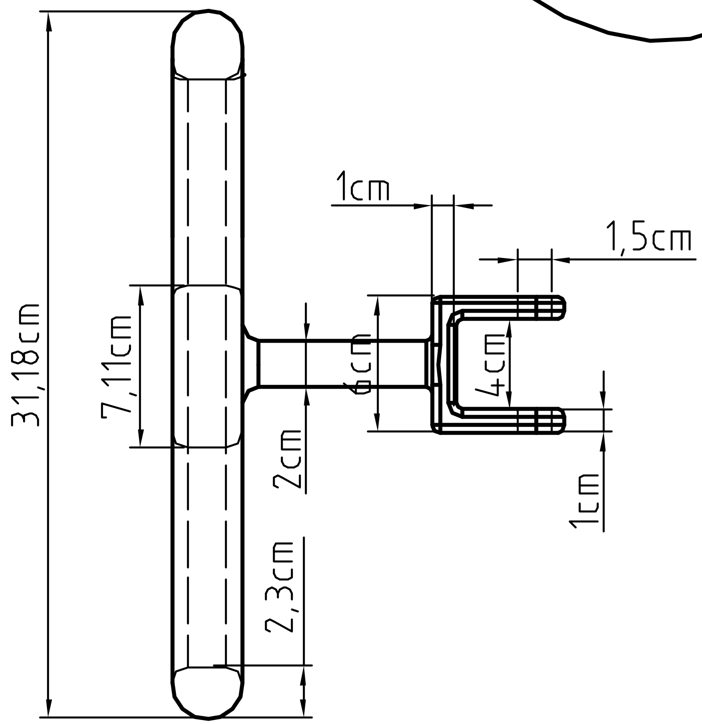


2,5cm
1,5cm
2,51cm
7,33cm





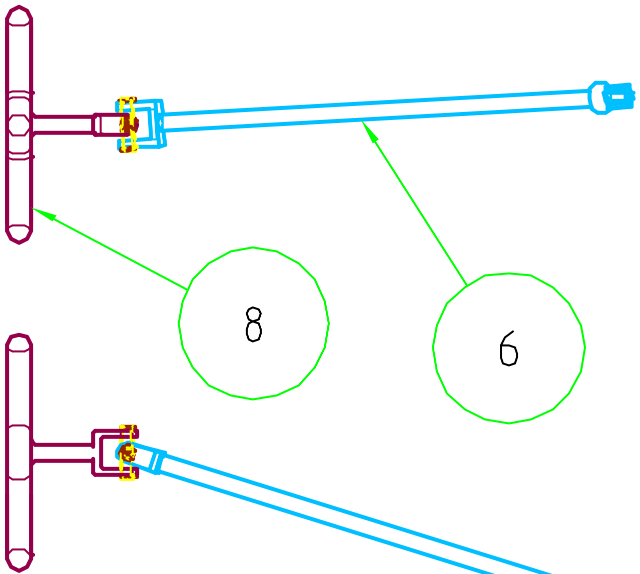
85°
1,25cm
ϕ2cm
3cm
6cm

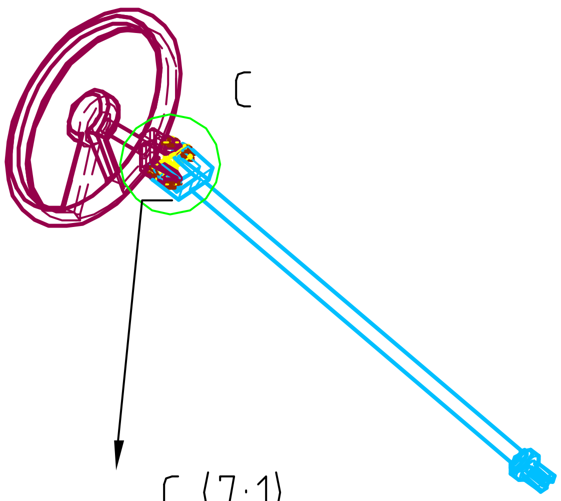


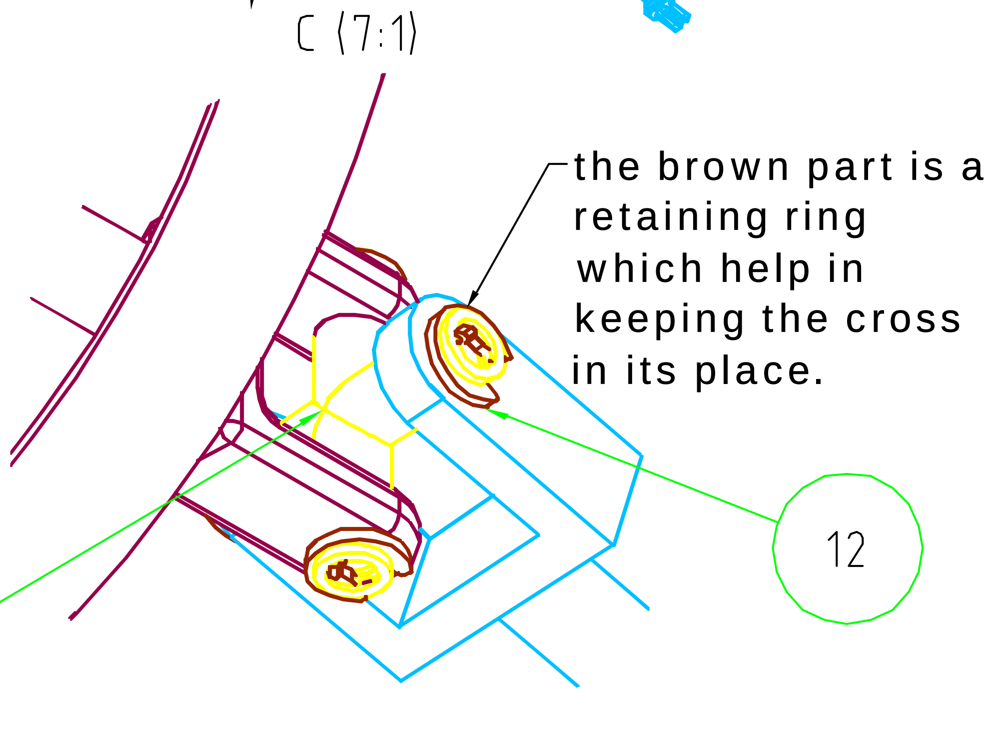
1cm
1,5cm
31,18cm
7,11cm
6cm
4cm
2cm
1cm
2,3cm

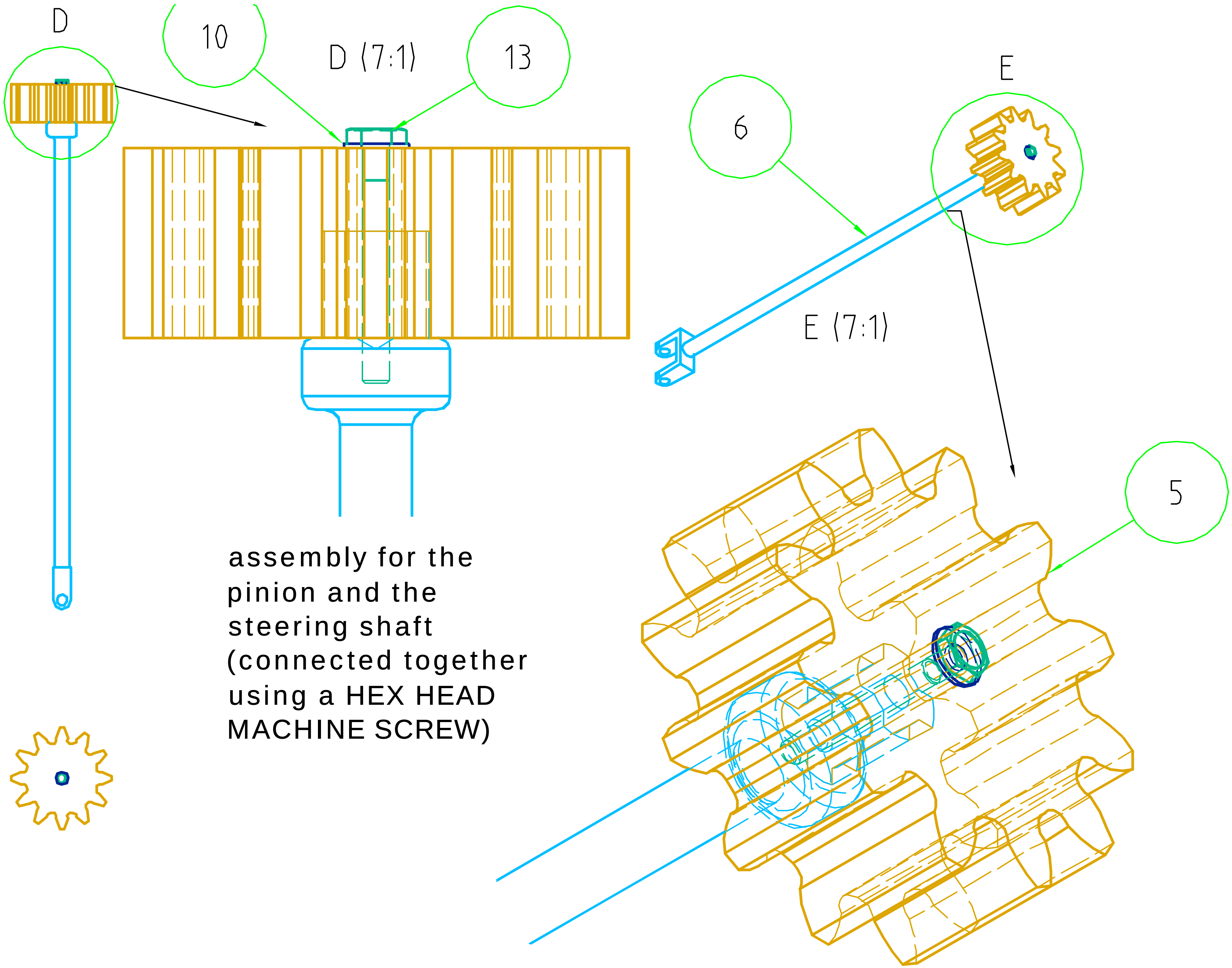
Parts List				
Name	Item	Qty	Description	Standard
RACK SHAFT	1	1	the shaft has one degree of freedom to push the tie rod and its driven by a pinion	DIN m=4 mm, T#52, pressure angle= 20 deg, addendum coef=1.25, root circle coef= 1.25
tie rod	2	2	connect the rack with the axel and insure and 3 rotational degree of freedom	standard tie rod design
ball socket	3	4	splited half part of a ball socket assembly which contain the ball from the tie rod to provide a 3 degree of freedom rotation	standard ball-socket design
pinion	5	1	transmit the rotational movement from the steering shaft to a linear movement on the rack shaft	DIN m=4 mm, T#23, pressure angle= 20 deg, addendum coef=1.25, root circle coef= 1.25
steering shaft	6	1	transmit the rotational movement from the steering to the pinion	60 cm length
universal joint	7	1	the cross which connect the steering to the steering shaft	standard universal joint design
steering	8	1	this part make it available for the driver to rotate the pinion and so to control the direction of the car	based on organamech factors
HEXAGON FIT SCREW - DIN 609 - M8 X 25	9	8	Hexagon Fit Screw	DIN 609 - M8 x 25
WASHER - ISO 7089 - 1.6 - 140 HV	10	11	Washer	ISO 7089 - 1.6 - 140 HV
HEX NUT - ISO 4032 - M1.6	11	8	Hex Nut	ISO 4032 - M1.6
E-RING EXTERNAL - TYPE-3CM - ANSI B27.7 - 1	12	4	E-Ring External - Type-3CM	ANSI B27.7 - 1
SLOTTED INDENTED REGULAR HEX HEAD MACHINE SCREW - UNC |REGULAR THREAD - INCH| - ANSI B18.6.3 - NO. 3 - 48 - 7/8	13	1	Slotted Indented Regular Hex Head Machine Screw - UNC |Regular Thread - Inch|	ANSI B18.6.3 - No. 3 - 48 - 7/8
RIGHT AXEL	14	1	link the tie rod to the right wheel	standard axel design
LEFT AXEL	15	1	link the tie rod to the left wheel	standard axel design
THRUST BALL BEARING - ANSI/AFBMA 24.1 TA - 6TA12 6 X 20 X 9	16	2	Thrust Ball Bearing	ANSI/AFBMA 24.1 TA - 6TA12 6 x 20 x 9
LARGE HEX HEAD MACHINE SCREW - UNC |REGULAR THREAD - INCH| - ANSI B18.6.3 - 1/4 - 20 - 1 1/2	17	2	Large Hex Head Machine Screw - UNC |Regular Thread - Inch|	ANSI B18.6.3 - 1/4 - 20 - 1 1/2
HEX FLAT NUT - ANSI B18.2.2 - 1 3/8 - 6	18	2	Hex Flat Nut	ANSI B18.2.2 - 1 3/8 - 6

assembly for the universal joint connection with the steering and the steering shaft, which help in varying the angle of the steering relative to the steering shaft



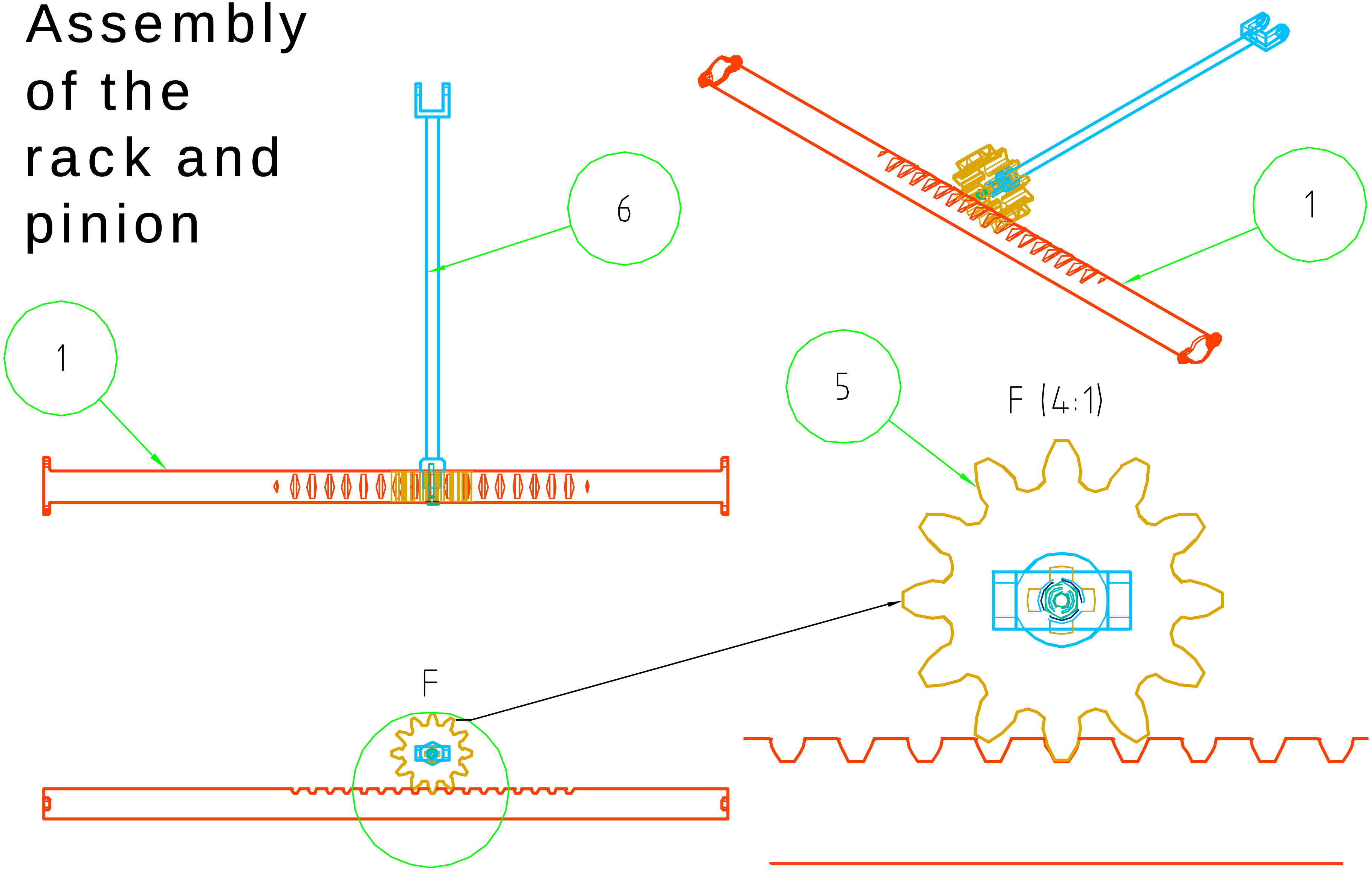




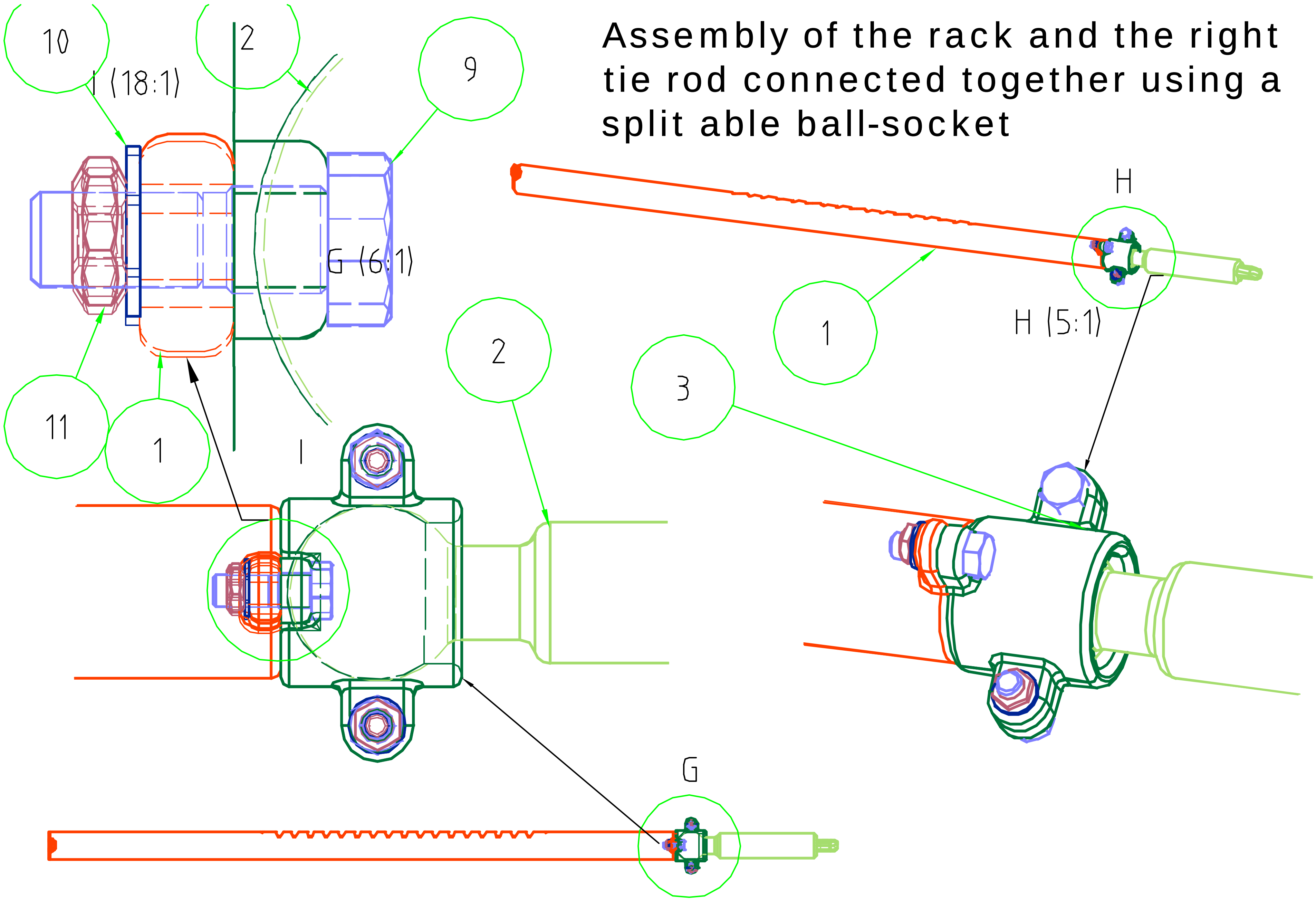


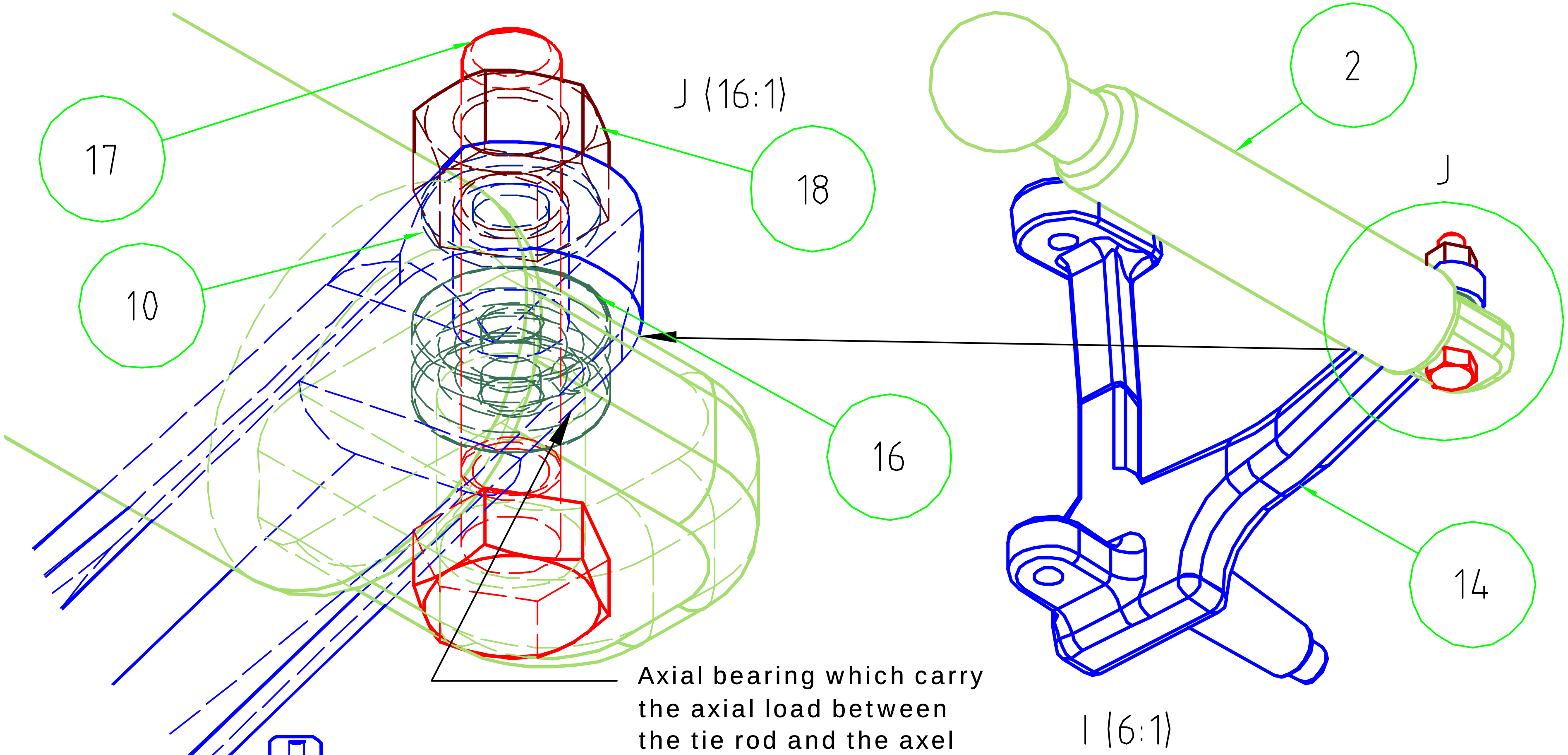
assembly for the
pinion and the
steering shaft
(connected together
using a HEX HEAD
MACHINE SCREW)

Assembly of the rack and pinion

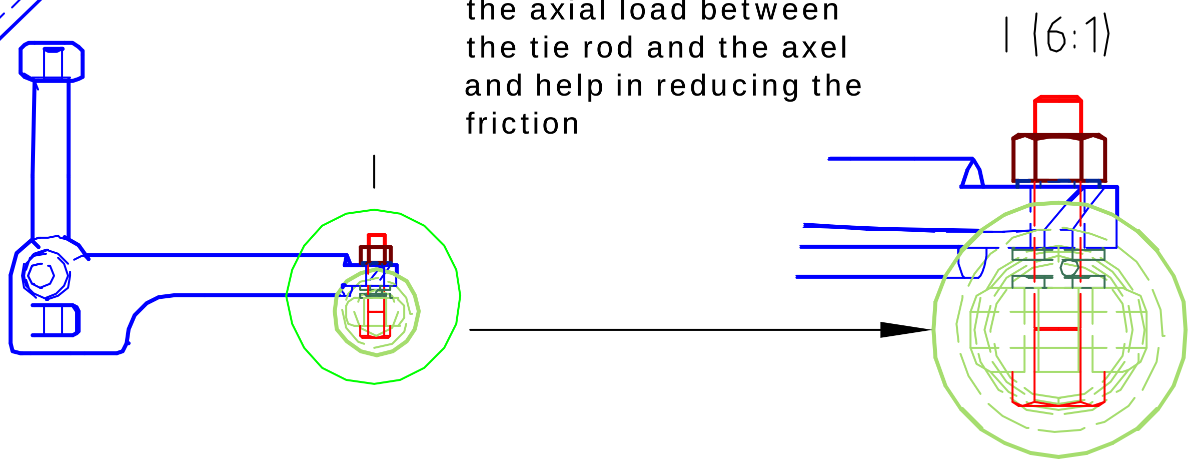


Assembly of the rack and the right tie rod connected together using a split able ball-socket



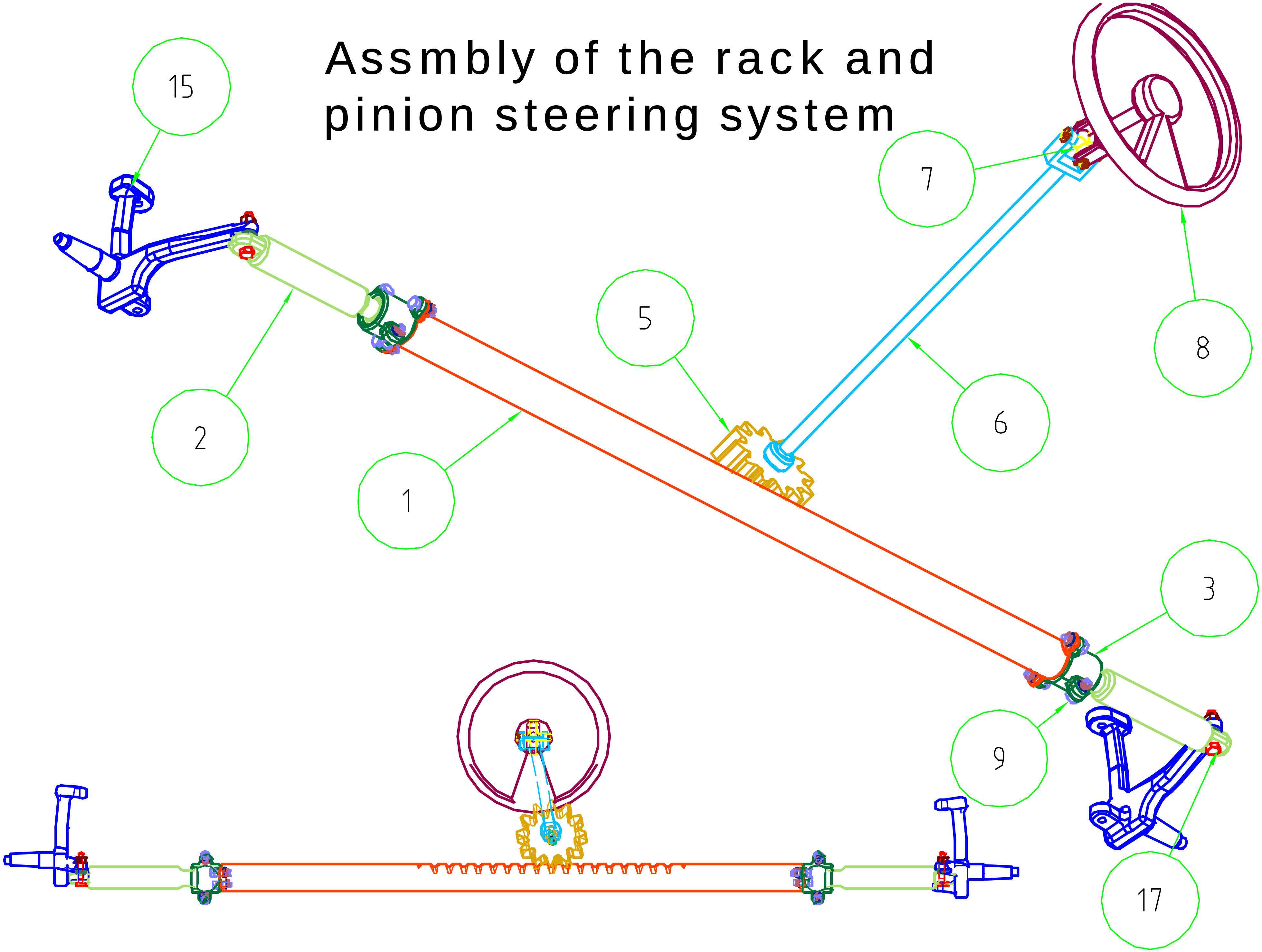


Axial bearing which carry the axial load between the tie rod and the axel and help in reducing the friction

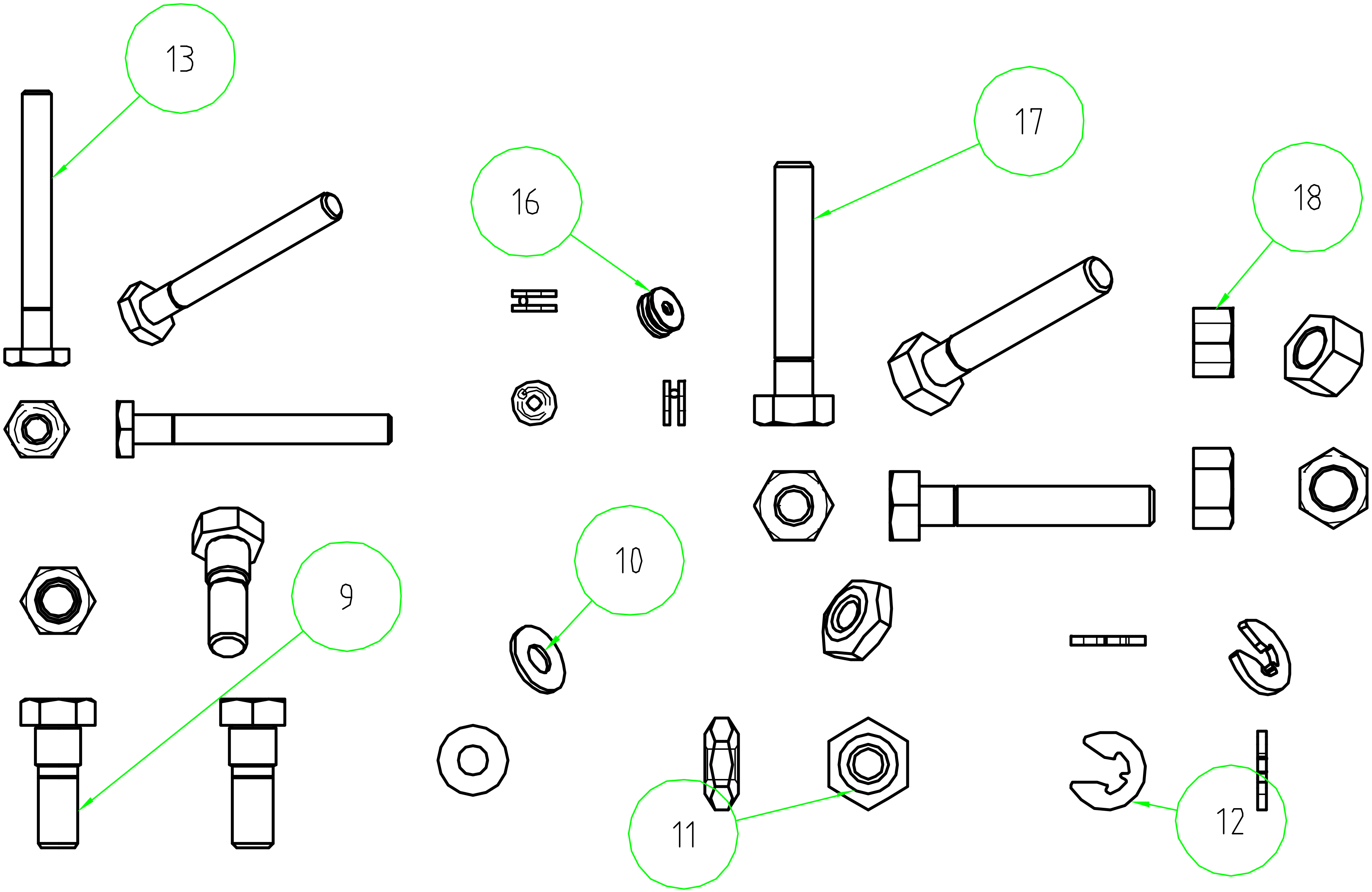


assmbly of the tie rod connection with the axel (the figure also shoe the axial bearing between tie rod and axel)

Assmbly of the rack and pinion steering system



FASTENERS AND SCREWS FOR THE STEERING MECHANISM



A future look.

This design data and analysis of is only a start in the long and complex way of designing and manufacturing a car, which could compete with other on road cars. But in my opinion no one can really understand and add on the more complex mechanism without pass through the starting point and understanding thoroughly the basic functionality, and the theory behind the basic design. So this starting point is the most essential factor in any designing process.

The next step in designing the complete car is to the design the complete rear and front axles, then the back axe and transmission gear, which also includes the linkages between them. The selection of a motor will help in both designing the gear transmission and the back axe. This selection will include also a generator set, a battery set, an exhaust system, gasoline tank and car accessories. Then will come the selection for the right fasteners. After that will be the auditing process on all the designing processes which include a through checking of the design data and measurements. Finally will be the manufacturing and assembling of the parts to form the complete car (product).

Conclusions & learned lessons

Two reasons make me choose this project. First is that cars industry forms the major part in industry around the world, due to its wide range of areas that is used in. Second is that the car it self form a fertile environment of learning and studies for any mechanical engineer with the various mechanical parts and systems it includes.

The project starts just from an idea of making a small, low cost car, and then the project goes harmonically with the question (what is the steps needed to make a car?). First, a shape for the car is needed to visualize it in mind, then determining a specific function for the car help in making decision of what will be the shape and what will be a better design for the parts. The shape of the car require the design of the chassis, the chassis determine in bold lines the dimensions and the capacity of the car. This lead for designing a suitable suspension system,

which could be built on that chassis, with taking in consideration that the car will function as an off-road buggy car. The design of a suspension system make it possible to design the steering system which is essentially connected to the suspension system. And this was the last step in this project hoping to continue the project later on.

I learned a lot from this project about how to synchronize my work, and how to think scientifically and logically about every difficulty that faced me. The project helps me also to learn how to make analysis to the problem in front me and how to choose the best solution for it. The project also gave me the ability to have a wider and clearer look to the theory behind mechanisms and help me to think how a mechanical engineer should think.

I also had constructive skills in many mechanical engineering software and applications due to the working on the project such as mechanical desktop, working model, cosmosm, AutoDesk inventor and think design.

I had some minor troubles due to my inexperience in the real mechanical parts shapes, standards and means of connections, also because of the unavailability of these parts in the university as the education here focus on the theory aspects only. Another problem faced me in the long computation time for the software, especially in the finite element analysis processes, the assembling of the parts and the motion analysis for the big mechanisms.

Finally, I would heartily thank Dr. Samer Mas'oud for his supporting to me from the starting point in this project and for accepting my basic concept and integrating it to an existing mechanism, which would never have been done without his vital advices at the most critical points. As I hope that, this project will meet your expectation to me.

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