CAREER EPISODE 1

INTRODUCTION:

Time duration	September 2009 to June 2011
Location	Moscow, Russia
Organization	Bauman Moscow State Technical University (BMSTU)
Project	Compact City Car
Position	Design Engineer

CE 1.1

This career episode relates to project titled **“Development of Compact City Car’’**. The project was carried at Bauman Moscow State Technical University (BMSTU).

In the first career episode I would like to describe a project that I did when I was studying at Bauman Moscow State Technical University (BMSTU). During the beginning of the project, I started working in Research and Manufacturing Center “Special Machinery” of BMSTU. This university organization specializes in the design and assembly of special civilian and military prototype vehicles.

BACKGROUND:

CE 1.2

With a general increase in the number of cars up to 10% per year, the level of car ownership over the decade will almost double. Obviously, in the foreseeable time, the development of the road network in most major cities will not allow to avoid congestion on the streets, even with the existing level of motorization. The small capacity of the road network, the insufficient number of intersections of highways at different levels and the concentration of places of mass gravity of the population in the city center lead to the fact that citizens lose tens thousands of hours on the streets. Under these conditions, the car is increasingly losing its main advantage - accessibility by time or movement.

CE 1.3

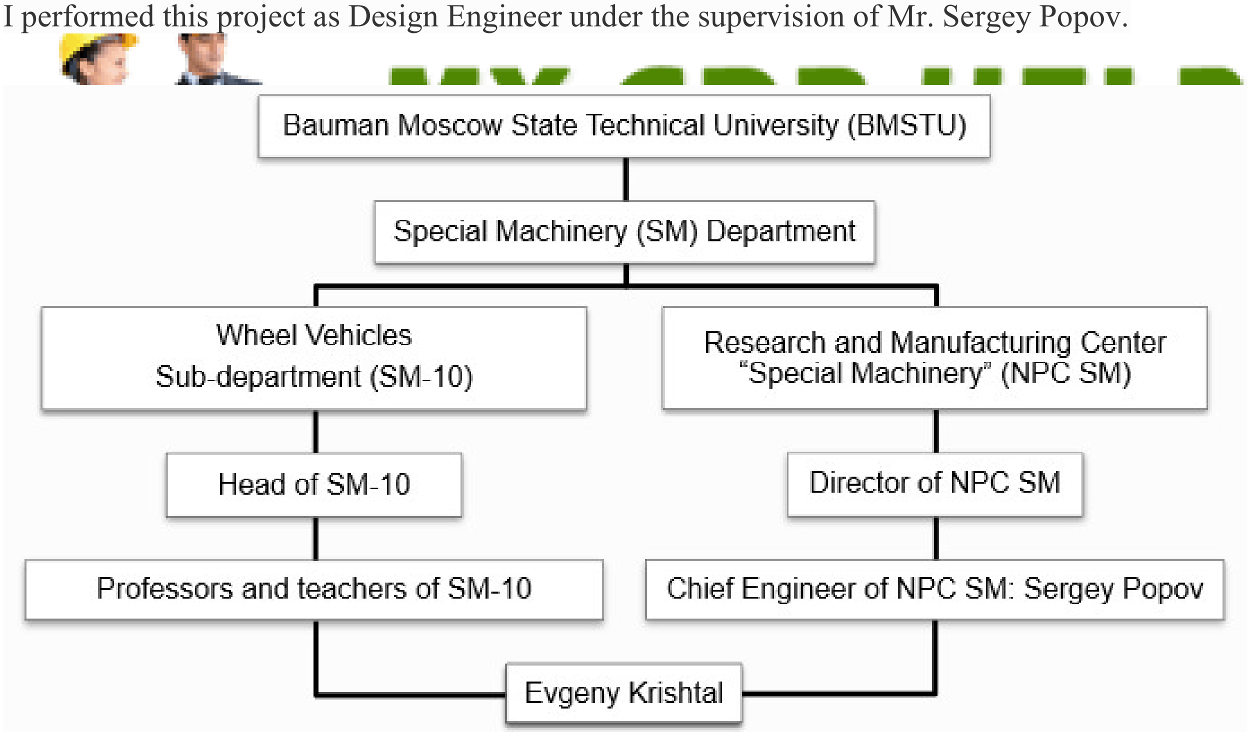
The main objective of this project was development of a general layout, structural and suspension system. The specific objectives of this project were:

➢ Development of vehicles layout and driver's place with minimal external dimensions.
➢ Obtaining of traction dynamic characteristic and optimum load characteristics of the elastic and damping devices of the suspension. Simulation of vehicle movement under different conditions.
➢ Engineering design of the suspension guiding apparatus and vehicle structural system.
➢ Development of the frame assembly process by welding and building berth for assembly by welding
➢ Evaluation of the prototype cost and its operating costs. Competitiveness assessment compared with competitors.

CE 1.4

I did this project individually with the support of both production center employees and my teachers. To complete the project successfully, I used to meet with them at least once in a week and discuss the accomplished tasks, tasks to be performed next weeks and problems faced. In addition, I used to meet my supervisor every Friday to submit the progress report and for proper guidance. I completed this project by following all the norms and ethics of a professional engineer.

I performed this project as Design Engineer under the supervision of Mr. Sergey Popov.



PERSONAL ENGINEERING ACTIVITY

CE 1.5

My Roles & Responsibilities

I performed following tasks in this project:

- Prepared and executed calculations
- Simulation Modeling
- Strength analysis by finite element method
- Prepared drawings and 3D models of parts and assembly units.
- Ensured compliance of the developed designs with specifications and standards.
- Prepared materials for contractual and budget documentation.
- Searched and participated in negotiations with manufacturers of components.

CE 1.6

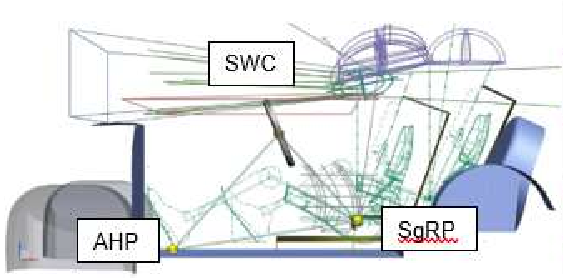
Ergonomics & Labor Protection

After receiving the initial technical requirements for a small-sized urban passenger car, I analyzed huge amount of information such as some materials on the recommendations of my supervisor and my teachers, and from other sources, such as regular visits to automobile exhibitions and searching for information in the Internet. Having studied the advantages and disadvantages of various designs, models and methods of calculation, I chose and used the most appropriate for my project.

Dimensions of the projected car were in between a motorcycle and a compact car. The need was to comfortably fit people within a short wheelbase while maintaining minimal outer dimensions required non-standard layout solutions. Therefore, I used a “semi-tandem” layout, ensuring the most efficient use of the horizontal projection area of the car with the minimum body width.

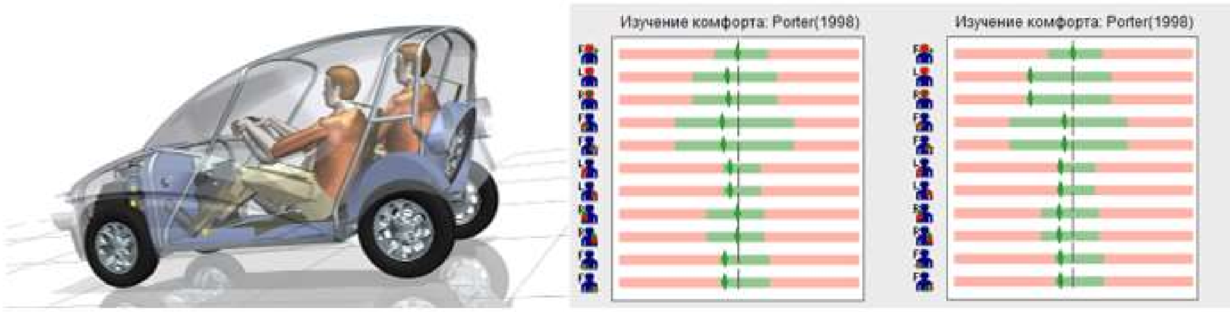
I carried out Car design in 3D-modeling system Unigraphics (Siemens) NX using virtual dummies:

- 2D dummy is for the initial development of cars
- 3D dummy is for evaluate the comfort of the resulting layout



Status	Verification item	Range	Value
✓	SgRP, degree	50.67 ~ 69.64	56.77
✓	SWC, degree	45.00 ~ 55.00	47.53
✓	AHP, degree	80.55 ~ 85.55	84.53
✓	AHP-SWC, mm	720.40 ~ 800.00	738.82

Initial layout and evaluation of 2D-dummies

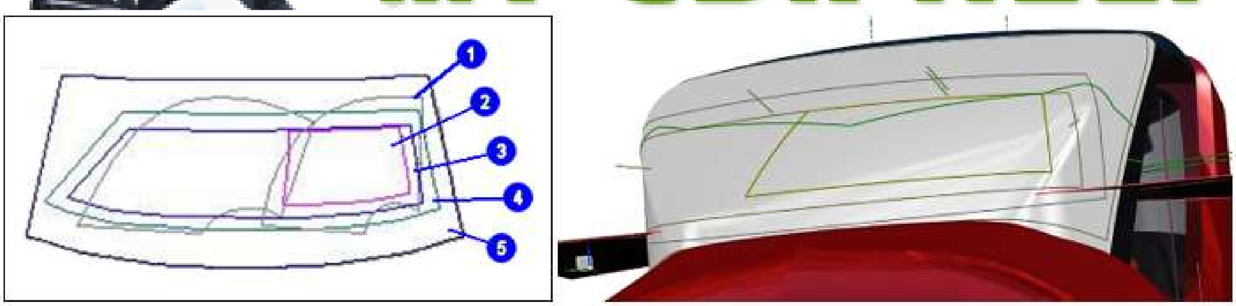


Evaluation of 3D-dummies: driver (left) and passenger (right). A zone of discomfort is shown in red on the histogram.

I considered the obtained position of the dummies was most optimal both in terms of meeting CAE standards and comfort in accordance with the survey database Porter 1998 with the minimum height of the seat position above the car floor. The latter was necessary to improve the transverse stability of a narrow car.

Visibility through the windshield was determined by the conditional zones on the glass outer surface. I checked the windshield and windshield wipers for compliance with standards by the master-process "Windshield viewing" of Unigraphics NX.

The lateral angle characterizing the non-visible zones formed by the front windshield pillars should match by the recommendations of SAE J1050 and EEC 77/649 standards.



Displaying the result of view areas on the windshield (SAE J902)
1 - Glass cleaning area; 2 - Checking area C; 3 - Checking area B; 4 - Checking area A; 5 - Windshield

Status	Verification item	Range	Value
✓	Barrier angle	<= 6.00	4.75
✓	Eye angle	<= 30.00	30.00
✓	Head angle	<= 60.00	15.77

Estimates of non-visible area

After the developed overall layout I proceeded to the calculation and selection of the main vehicle components.

Engineering Simulation & Calculations

CE 1.7

Traction-Dynamic Calculation

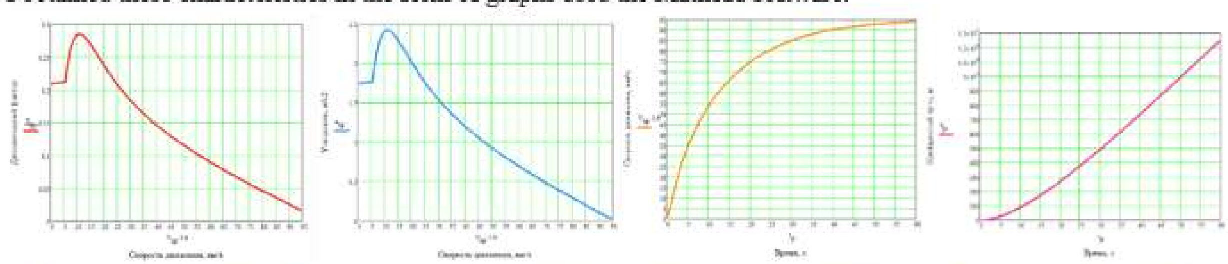
Projected car was the vehicle L6 / L7 category ("quadricycle" is defined by Framework Directive 2002/24/EC). Quadricycles have limitations on engine power (4 kW / 15 kW) and curb weight (350 kg / 400 kg), but there are fewer technical requirements for them than cars. For example, they can use motorcycle or industrial internal combustion engines.

As one of the optimal in power and price, I chose the industrial diesel engine of local production. It had a maximum power of 13 hp and maximum torque of 27 Nm. I also chose local CVT (variator) as transmission. Using the obtained masses of people, components of the power unit and the maximum curb vehicle weight, I calculated the approximate mass and its distribution along the axes for various cases:

- Minimum weight – with Driver (Woman 5%)
- Average weight – with Driver (Man / Woman 50%)
- Maximum weight – with Driver (Man 95%) and Passenger (Man 95%)

I calculated three parameters for traction-dynamic evaluation: Dynamic, Acceleration and Speed characteristics.

I obtained these characteristics in the form of graphs used the Mathcad software.

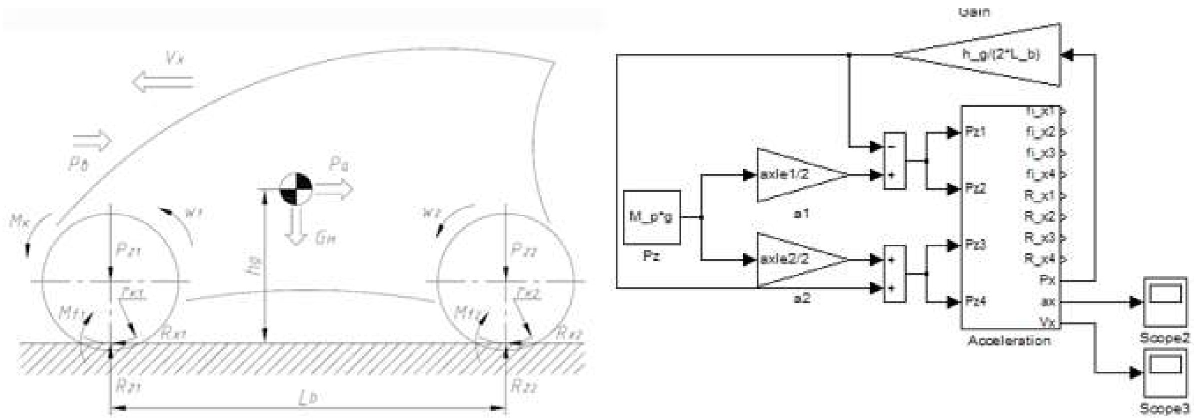


Dynamic characteristic (Dynamic factor on speed), Accelerating characteristic (Acceleration on speed) and Speed characteristic (Speed on time and Traveled Distance on time)

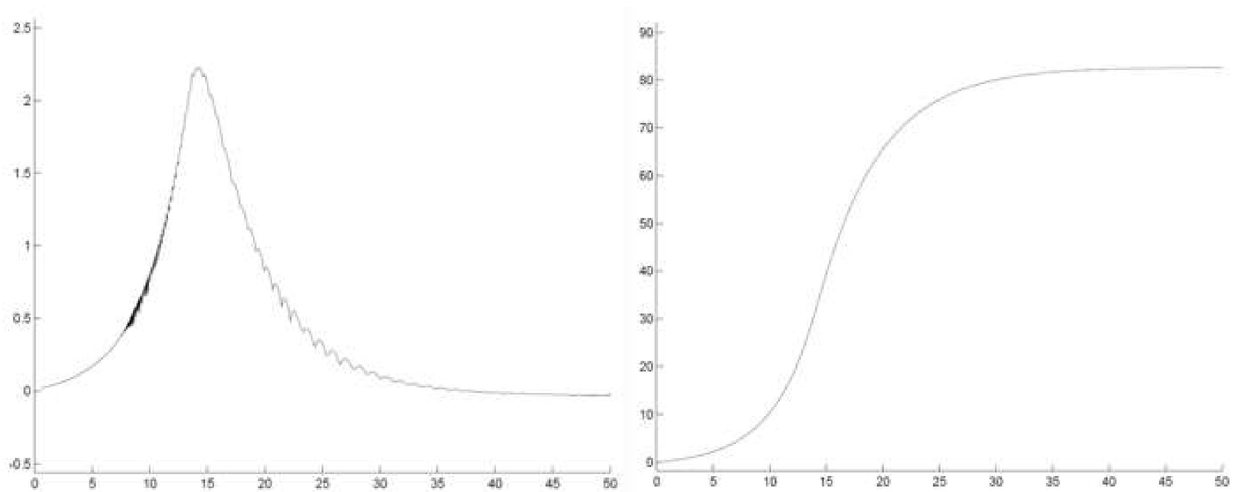
CE 1.8

Simulation

The next step was the simulation of linear motion on a tarmac road using MATLAB software. I performed this simulation after the previous stage to obtain more accurate characteristics and use for the next calculations. Here adhesion coefficient depends on both movement speed and slip coefficient. After the simulation, the system built Accelerating and Speed characteristics.



Design diagram of the linear motion on a solid flat surface and scheme of subsystem “Linear motion”



Acceleration characteristic ax(t), m/s², and Speed characteristic vx(t), km/h, depending on acceleration time

Results of the traction dynamic calculation

Parameter	Calculation in Mathcad	Simulation in MATLAB
Maximum longitudinal acceleration, m / s²	2,4	2,2
Maximum speed, km / h	94	83
Acceleration time up to 60 km / h, sec	12	18
Acceleration time up to 80 km / h, sec	25	30

I concluded that considering the change in the adhesion coefficient due to speed and slip somewhat reduces the car dynamic characteristics on average by 15%.

CE 1.9

Spectral Method of Calculating the Suspension System

Suspension system is a set of devices that provide an elastic connection between vehicle frame and wheels and is designed to reduce the intensity of vibration and dynamic loads, and consists of guiding, elastic and damping devices.

At the initial design stage, as indicators of the vibration-insulating properties of the suspension, i.e. smooth ride can be using the natural frequencies of the car sprung mass and the relative damping factor.

Reduce stiffness coefficient of an elastic element:

$$c_{п} = 4\pi^2 f_z^{\,2} m_{12}.$$

Reduce resistance coefficient of a shock absorber:

$$k_{п} = 4\pi\psi_z f_z m_{12}.$$

Where:

f_z	natural frequency of vertical oscillations of the mass of the sprung machine part; =1,25 Hz
m_{12}	mass of the sprung vehicle part, kg
ψ_z	relative damping factor; =0,25

Constant smooth ride is ensured in the case of the following inequality:

$$c_{п} h_{z.дин} < (m_{\max} - m_{max})g;$$

Where:

$m_{\max}$	maximum sprung vehicle mass when driving
$m_{\min}$	minimal sprung vehicle mass when driving

Dynamic suspension deflections:

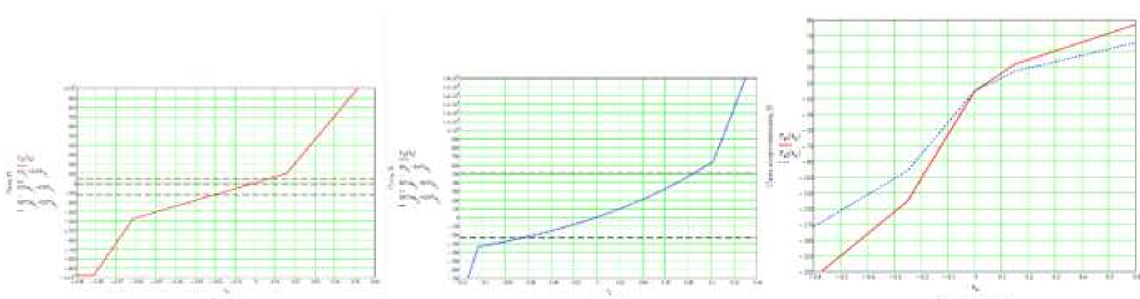
$$h_{z.дин} = k_{дин.h} \times h_{z.стат} = k_{дин.h} \times \frac{P_{z.стат}}{c_{п}}$$

Where:

$k_{дин.h}$	dynamic factor; =0,3
$P_{z.стат}$	vertical static load on a wheel from sprung part

After calculations, I received load characteristics of elastic and damping devices and full deflections, which were equal to 135 mm for the front and 246 mm for the rear suspension.

This and further calculations and characteristics associated with the suspension system were done and built by me using the Mathcad software.



Load characteristics of elastic (left) and damping devices (right) for front (red) and rear (blue) axles

Determination of load regimes indicators

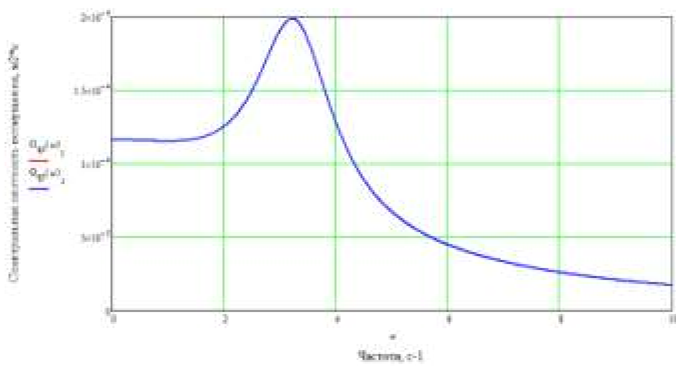
The micro profile, consisting of irregularities (wavelength from 10 cm to 100 m), has a decisive influence on many operational properties of the vehicle, and is presented as a random function. The equation of spectral density of heights of irregularities, which characterizes the frequency composition of the road surface micro profile:

$$G_q(\theta) = 4D_q g_q(\theta).$$

Where:

D_q	approximation coefficient of the road surface micro profile correlation function
$g_q(\theta)$	normalized spectral density of heights of irregularities of a road surface (micro profile)

After multiplying it by frequency response smoothing ability of the tire, I received spectral density of the disturbance from the road surface.



The spectral density of the disturbance regarding the smoothing of the tire

CE 1.10

I did simulation of suspension system while moving on a cement road using MATLAB software. This simulation was done after the previous stage to check the normative indicators.

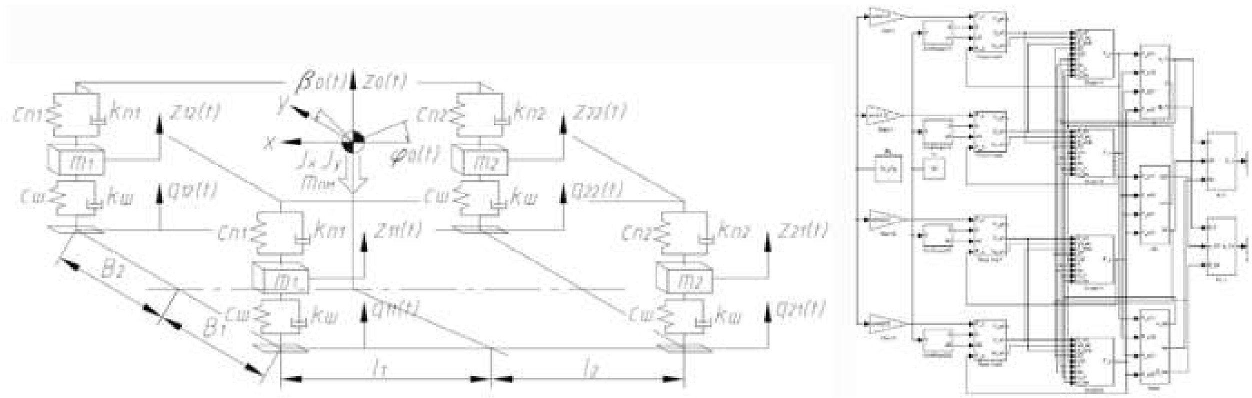
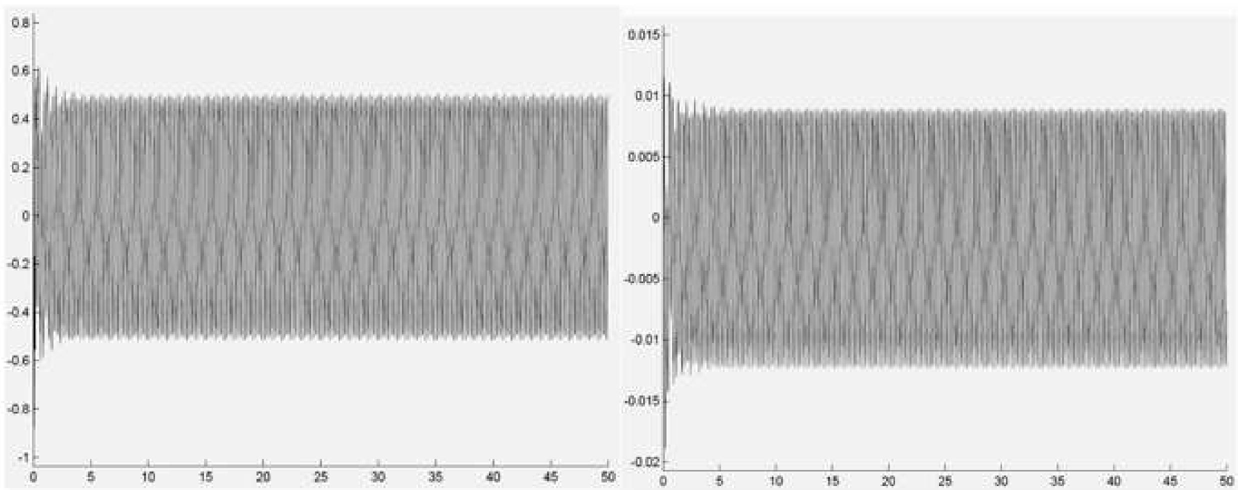


Diagram and Model of a dynamic system equivalent to a vehicle suspension system



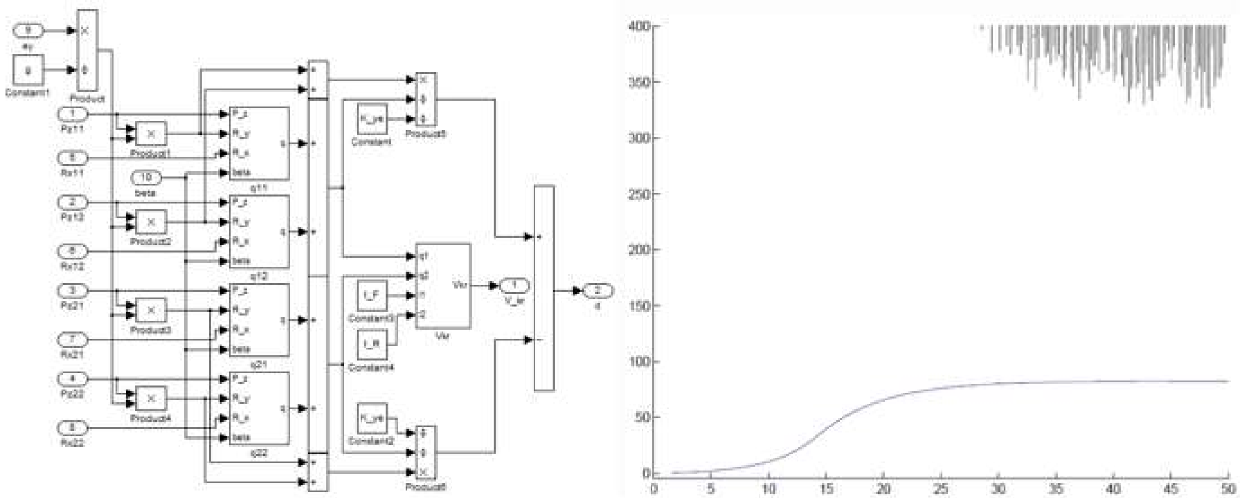
Vibration accelerations (left) and vertical movements (right) at the driver's seat

After the simulation, the system-built graphs of vibration accelerations and vertical movements. It was received that the vibration accelerations at the driver's seat did not exceed 0,5 m / s^2, which was less than the normative value by more than 1,5 times.

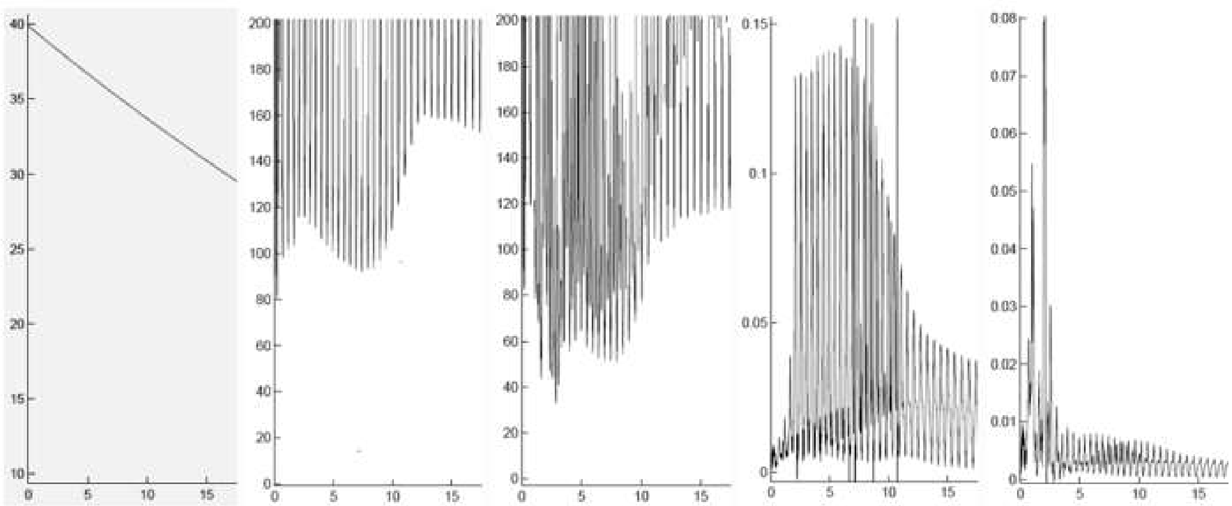
CE 1.11

<u>Calculation of critical speeds using MATLAB Simulink</u>

For the simulation of tests for the motion stability I used the previous Model of a dynamic system with the addition of subsystem "Critical movement speed".



Subsystem "Critical movement speed" and graph of Acceleration characteristic and critical speed when rectilinear motion



The resulting graphics from left to right: Vehicle speed at steady motion; Critical movement speed (km / h) in simulation tests “turn R = 35 m” and “lane-change S = 16 m” (right); Difference between the slip angles of the front and rear axles (degree) in simulation tests “turn R = 35 m” and “lane-change S = 16 m”

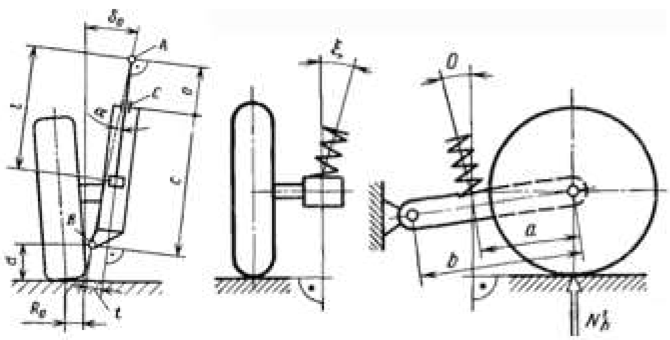
I deduced following aspects from the simulation results:

- During acceleration the critical speed does not exist
- In the case of rectilinear steady-state motion, the critical speed is not less than 300 km / h
- When steady motion in a turn, the critical speed is more than 90 km / h and difference between slip angles of the front and rear axle does not exceed 0,15°
- When steering wheel is turned sharply, the critical speed decreases to 40 km / h and difference between slip angles of the front and rear decreases to 0,08°

CE 1.12

For the front axle, where the wheels turn, I chose MacPherson suspension. However, this was not enough, since in this suspension type the lower arm is attached at two points. Therefore, I used the connected longitudinal arms as the lower arms, which allowed using only one fastening point.

For the rear axle, where it is necessary to ensure a sufficiently large wheel displacement, I chose suspension on the longitudinal arms, which made it possible to perform the low flat floor of the body above suspension. This means that the passenger seat can be placed almost above the rear axle, which make the length of the wheelbase minimal.



Design scheme of the front and rear suspension

CE 1.13

Analysis of technical requirements for manufacturing

I chose semi-automatic gas-shielded welding, because unlike automatic submerged arc welding and manual coated electrodes, it has the following advantages:

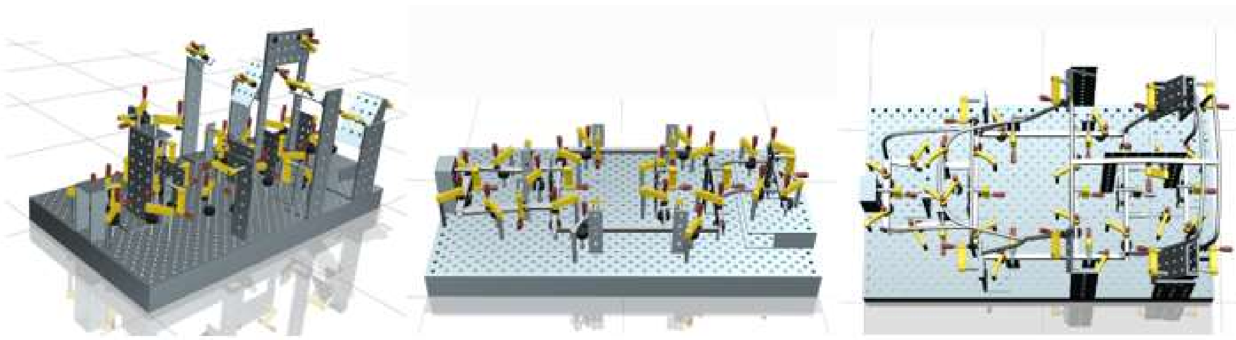
- strong degree of protection of the molten metal from the influence of air;
- possibility of conducting the process in all spatial positions;
- possibility of visual observation of the stages of the formation of the seam and its regulation;
- more efficient process performance than manual arc welding;

Assembly process

In determining the sequence of assembly and fitting work, special attention was paid to ease of assembly, minimization of special tools and assembly time, as well as the possibility of breaking up the product into its component parts, the assembly of which can be done independently of each other.

- Operation 005. Assembly and welding. Transition 1.
  Install the square section profiles on the building berth and fix it with the stops according to the sketch. Weld by GOST 16037-80-U17-UP.

- Operation 005. Assembly and welding. Transition 2.
  Fasten the round section profiles to the stack according to the sketch. Weld by GOST 16037-80-U17-UP.
- Operation 005. Assembly and welding. Transition 3.
  Install new fasteners on the stocks and fix the remaining profiles with them. Weld by GOST 16037-80-U17-UP.



Building berth and assembly process

CE 1.14

Economic Section

At this paragraph I evaluated of the prototype cost and its operating costs, as well as conducted a competitiveness assessment compared with competitors.

Cost calculation of each unit and whole car

Cost of basic materials and purchased components:

$$S_{\text{м}} = k_{\text{т}}\left(\sum_{i=1}^{m} G_{\text{м}i}\text{Ц}_{\text{м}i} + \sum_{j=1}^{n} \rho_j \text{Ц}_{\text{п}j}\right)$$

Where:

$k_{\text{т}}$	coefficient considering transportation and procurement costs, =1,2
$G_{\text{м}i}$	consumption rate of basic materials (cast and rolled parts), kg
$\text{Ц}_{\text{м}i}$	price of the basic material, ruble / kg
$\text{Ц}_{\text{п}j}$	price of purchased components, ruble

Total cost of production:

$$S_{\text{п.пр}} = \left(S_{\text{м}} + L\left(1 + k_{\text{ц}} + k_{\text{оп}}\right) + L\alpha + L(1+\alpha)k_{\text{с}}\right)(1 + k_{\text{ВП}})$$

Where:

L	basic wage costs, ruble
α	coefficient considering the cost of additional wages of workers, 0,15
$k_{\text{ц}}$	workshop cost factor, =0,35
$k_{\text{оп}}$	general production costs ratio, =0,11
$k_{\text{с}}$	coefficient considering deductions for the unified social tax, insurance premiums, =0,26
$k_{\text{ВП}}$	non-manufacturing expense ratio, =0,04

Calculation of annual operating costs

Annual fuel costs:

$$S_{т} = 0{,}01 Q_{Б} K_{год} (1 + D) C_{т}.$$

Annual lubricant costs:

$$S_{см} = S_{т} k_{см}.$$

Annual cost to restore tire wear:

$$S_{б.э} = \frac{Ц_{б.э.} k_{б.э} K_{год}}{W_{рес}}.$$

Annual operating costs:

$$S_{э} = S_{т} + S_{см} + S_{б.э}.$$

Unit reduced costs:

$$S_{прив.уд} = \frac{S_{э} + E_{р} C_{п}}{K_{год}}$$

Where:

$Q_{Б}$	average fuel consumption, l / 100 km
$K_{год}$	annual car mileage, = 20 000 km (in urban areas)
D	addition to the rate of fuel consumption for operation in winter conditions, =0,1
$C_{т}$	fuel price, ruble / liter
$k_{см}$	coefficient considering the cost of lubricants, =0,15
$Ц_{б.э.}$	cost of a set of 4 tires, rubles
$k_{б.э}$	coefficient considering the cost of repairing tires, =1,1
$W_{рес}$	guaranteed tire mileage under typical operating conditions, =45000 km
$C_{п}$	car price including VAT, rubles
$E_{р}$	normative coefficient of economic efficiency, = 1 / (useful lifetime) = 1 / 3 years = 0,33

CE 1.15

Engineering Problems

The first problem I faced in the project was designing the layout of vehicle where I encountered issues of comfortable accommodation of passengers, the location of the power plant while maintaining minimum dimensions. I studied different types of car layouts and first chose the tandem layout. After I tried to work through this layout, I found serious problem while accommodating a passenger.

If the passenger is provided with due comfort according to ergonomic requirements, the vehicle need to be long. To make the wheelbase small, the driver's seat is between the passenger's legs and such layout is simply unacceptable from the point of view of automotive and human standards, and also driving may be dangerous.

After analyzing layouts and human body, I determined and chose the most optimal layout. The widest part of the body is the shoulders. Therefore, by moving the passenger back a little, position of the people can be possible. As a result, the width of the car grew slightly, but while maintaining a small length, it was possible to meet the required comfort for the passenger.

Next problem I faced was providing lateral stability. Initially, when the tandem layout was being worked out, there was idea to develop and introduce compulsory tilt in the direction of a turn (like on Carver One). After the analysis of various tilting systems revealed that this system required both a complex hydraulic system and a control unit with sensors, because of what this reason it was too expensive for this class of car. Therefore, I decided to dwell on a simple and proven solution: minimize the seats height and equip the suspension with sufficiently rigid anti-roll bars.

CE 1.16

Summary

In this project, I was created a draft design of a two-seater car that had one of the smallest footprint areas, while satisfying all ergonomic norms and safety standards. Despite such small dimensions, I provided people in the cabin with the necessary space, guarantying comfort at the level of higher-class cars.

I developed a suspension system, which also had minimal dimensions and provided the best possible smoothness ride under given conditions. The results of the motion simulation showed that the car had a high smoothness ride, resistant to maximum transverse loads and had neutral steering with ensuring motion stability even in critical modes. The cost estimate showed a very low cost of creating a prototype in comparison with the cost of competitors, which indicated the real feasibility of this project.

This project was accomplished successfully and submitted on time due to continuous hard work by me and through regular support and guidance of the supervisor.