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THE SIMULATIONS AND THE ANALYSES OF THE SILESIAN GREENPOWER VEHICLE MOVEMENT IN NX 8.5 PROGRAM

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Abstract: The idea of The Greenpower Corporate Challenge race and actions taken by Silesian University of Technology in accomplishing the project of the car for the competition were presented in this paper. Past successes achieved in this field were also mentioned. Afterwards, stages of research on the electric vehicle model, which was prepared in NX 8.5 program by the Silesian Greenpower Team, were described step by step. Studies were focused on the analysis of car's position during overcoming the track. Firstly, the analysis of vehicle's understeering and over steering depending on given angle of wheel turn was conducted. Thereafter, the simulation of bolide movement on a track, whose estimated dimensions were gained with the use of GPS coordinates from one of races, was prepared.
Key words: Silesian Grenpower, race car, turning of vehicle, NX 8.5, Motion Simulation module.

1. INTRODUCTION

The main goal of The Greenpower Corporate Challenge (GCC) Race is to maximize vehicle range with a limited energy source over four hours. During construction of racecar, safety rules and dimension rules must be obeyed. Start of the vehicle may be supported by a two-step human push in order to prevent an initial high inrush current. Each team use an electric engine and batteries of the same type in order to even up all contestants' chances. Moreover, the use of recyclable materials in the vehicle development is one of the requirements.
In order to build a race car, students of Silesian University of Technology established the interfaculty team. In 2012 edition, the SG team managed to construct and build the brand new race vehicle. What's more, the earlier bolide was modernized. The race took place again at the Silverstone Circuit. In 2012, the SG team ended the race on the 1st place with its new vehicle and on the 2nd place with the older one. In addition, they beat the track record. [3]

2. THE RESEARCH ON THE RACE CAR MODEL PREAPARED IN NX 8.5 SOFTWARE

2.1 Model Preparations for the Purposes of Motion Simulation Module

During the last contest edition, the SG team prepared a 3D model of the constructed race car in CAD software. In order to use it properly in Motion Simulation module, some simplifications were made. Elements which have a minimal impact on vehicle turning were omitted because they could significantly complicate simulation process. Correctness of the entire assembly, especially setup of all elements, was verified in Assembly module of NX 8.5.
The main goal was conducting an analysis of the race car movement in conditions which imitate the real ones. It was crucial to assign material constants for each assembled element. In order to fulfill that, Assign Materials function was used (Fig. 1).
It enables to assign material from material library. Furthermore, it is possible to create custom materials. What's more, NX software uses associativity: all changes introduced in one module are automatically provided for the rest.
Masses of batteries and engine were also taken into consideration. In connection with the above, few primitive features were added into assembly. Masses of primitives were assigned indirectly with the use of Body Density function (Fig. 2). Driver's mass is also significant. It was provided with the use of another primitive - sphere. It was assumed that the driver's mass center is located in the vehicle's mass center.
Standard process of preparing simulation was carried out in Motion Simulation module. It covers:
a) division of mechanism into elements taking part in simulation (LINKS);
b) assignment of motion relations (JOINTS); in this case, Revolute Joint was added to the vehicle's wheels;

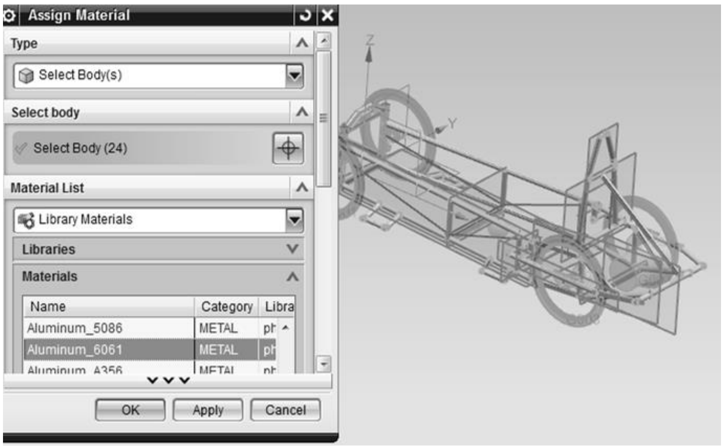

Fig. 1. Assign Material function

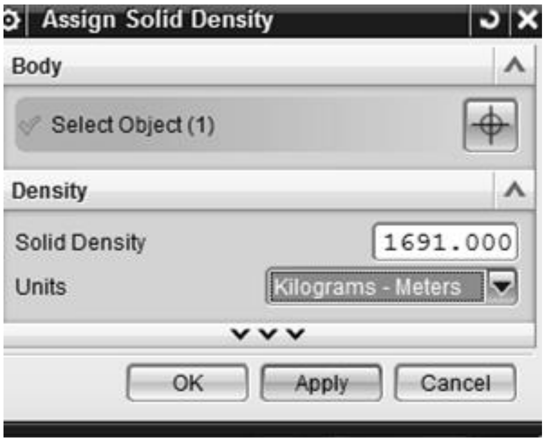

Fig. 2. Assign Solid Density function

c) assignment of 3D Contact connector: it enhances simulation reality and enables to imitate contact between defined elements; in this case, it was used between tire tread and asphalt surface of track; friction coefficient was also included with the value of 0.7 [6].

In the real vehicle, the left rear wheel is driven. In the simulation, torque was assigned to this wheel in order to simulate the engine work. Constant torque value was 10 Nm. The race car reached velocity of 57 km/h. Simulation parameters were: t=40 s and 400 steps. Those values determined sufficient simulation accuracy (Fig. 3).

In order to analyze simulation, charts of vehicle positions in XY coordinates for all three cases were generated. They show how real tracks differ from ideal circular paths specified for each wheel turn angle (Fig. 4).

Data extracted from simulations show vehicle oversteering . This effect occurs when rear axle is more loaded. It's unstable behavior because skid conditions caused by turn angle intensify. Such skid occurs commonly in Formula 1 because of wrong braking during turning. The analyzed SG vehicle has also the same tendency to tighten real turn radius during making such a maneuver. This tendency lasts until velocity is below 50 km/h for turn angle of 3^o. Centrifugal forces of inertia, which are high enough to bring the vehicle to understeering state, occur above this value of velocity. In this situation, the real turn radius is greater than assumed one. With the decrease of wheel turn angle, the limit of understeering phenomenon moves up, what enables to turn the bolide at higher velocity. It's easier to drive a car which is understeer than the over steer one. Proper mass distribution is crucial in the case of reaching drive conditions which are better to regulate.

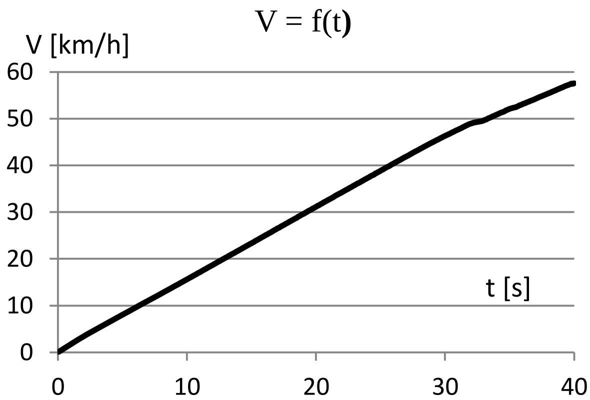

Fig. 3. Velocity of the race car

2.3 Preparing of the Circuit Model for the Purposes of the Second Stage of the Research

This step of the research was focused on reproducing The Good wood Circuit.

The 2,4 mile circuit is located near Chichester, West Sussex, close to the south coast of England. This is a place of historical importance for British motor sports and motorcycle racings. Formula 1 races took place here.

On a basis of data obtained from GPS transmitter during race in 2010 (Fig. 5), a model of race track was created in NX 8.5 program.

In the first place, geographic coordinates were converted into the metric system from World Geodetic System (WGS84). This process was carried out with assumption that globe is sphere (Fig. 6). This simplification didn't cause distortion of race track because of uniform calculation method for all points. Calculations were performed in spreadsheet.

Hardware and software limitations forced selection of only one part of the circuit for carrying out the analysis. The chosen one was the sharpest bend in the track - Lavant corner.

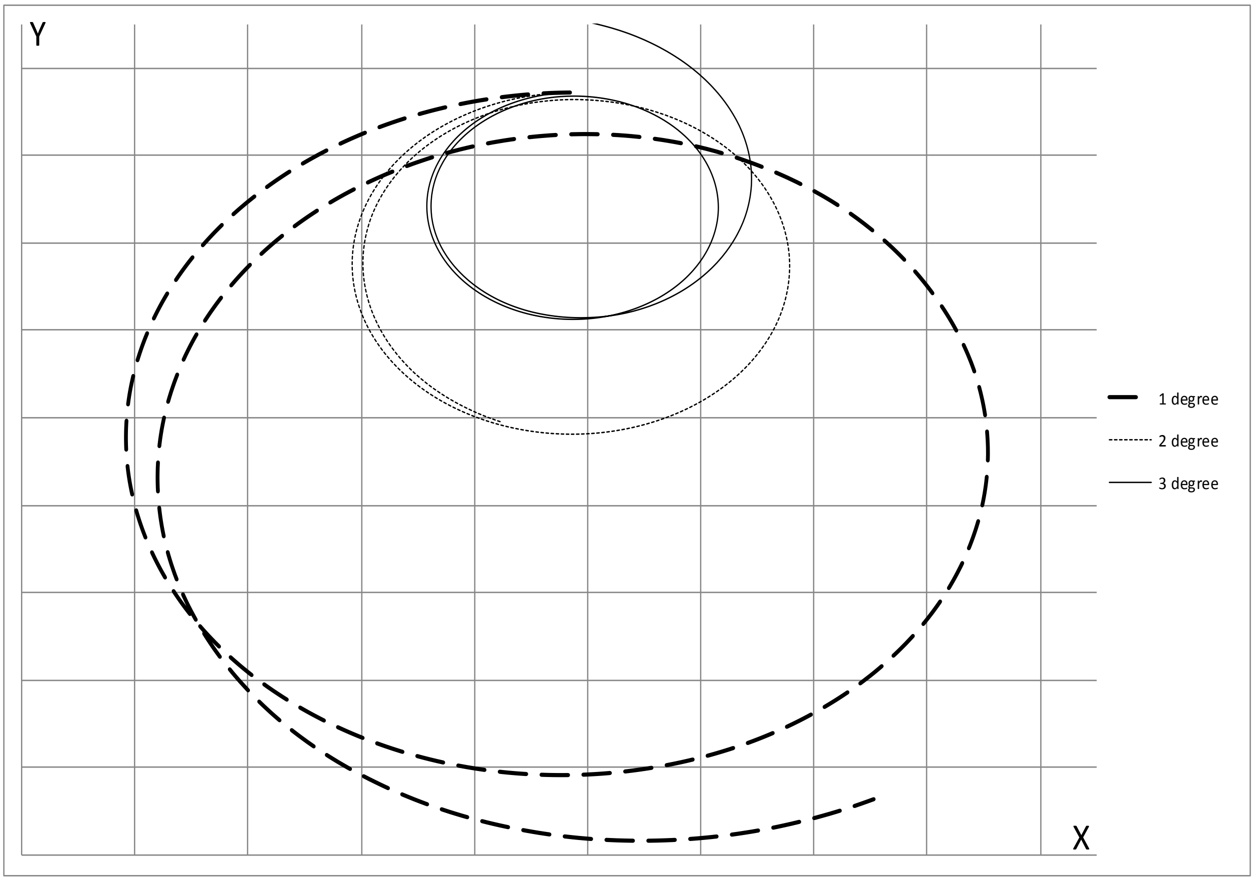

Fig. 4. Three cases of vehicle's positions during movement

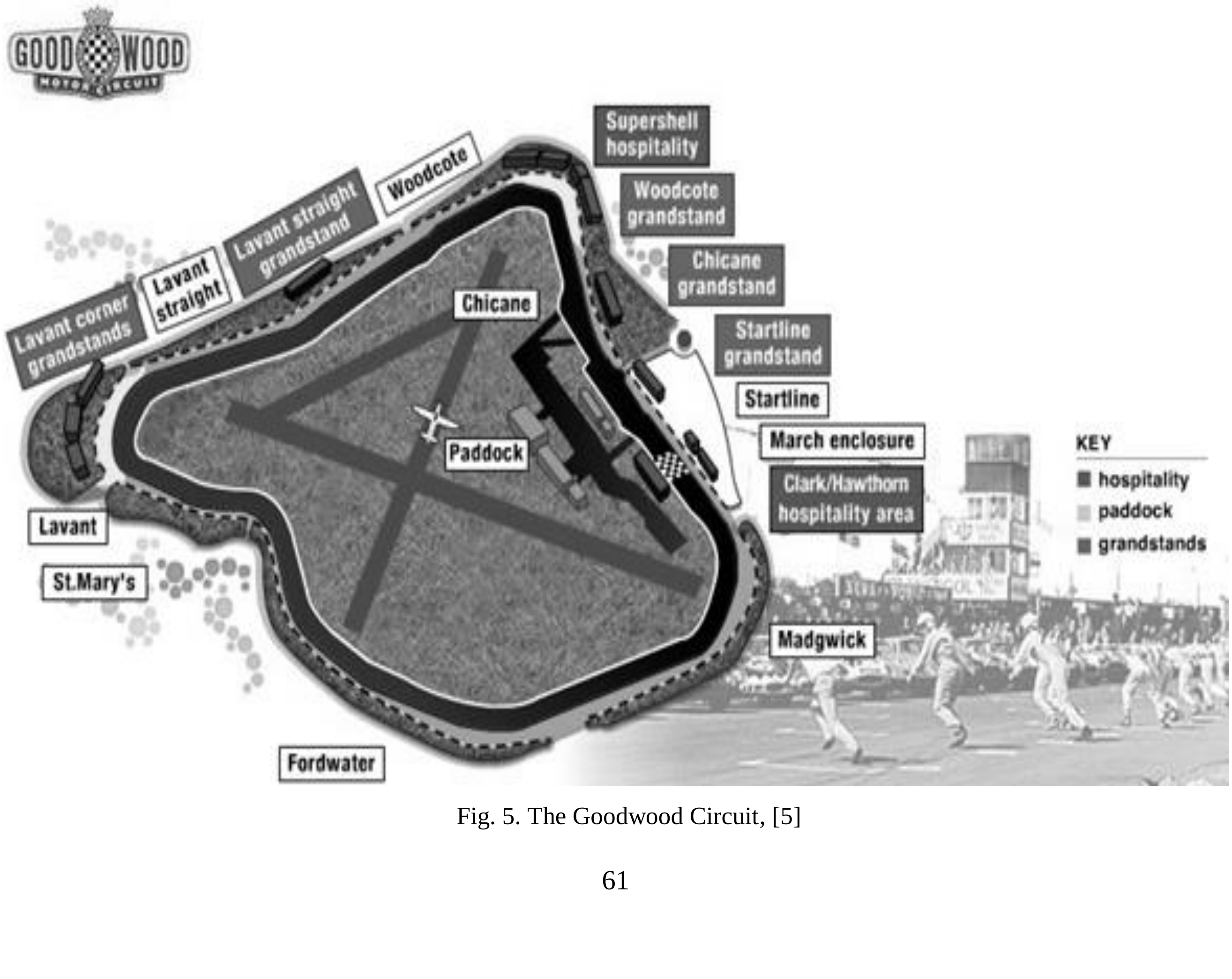

Fig. 5. The Goodwood Circuit, [5]

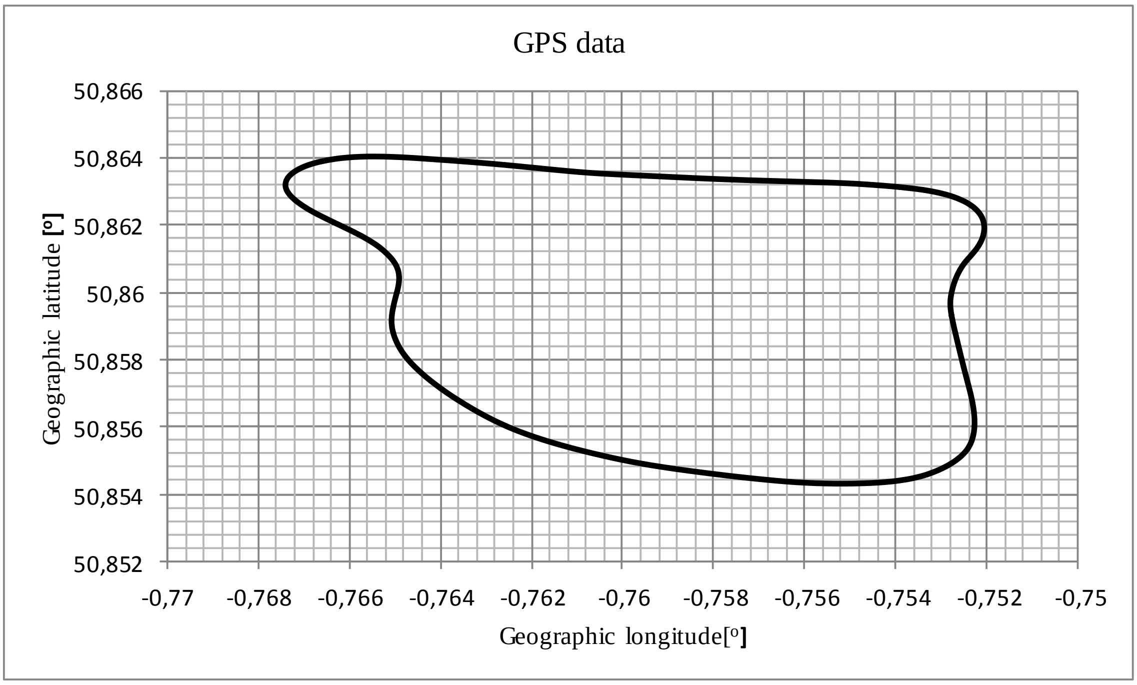

Fig. 6. Bolide passage from 2010 race

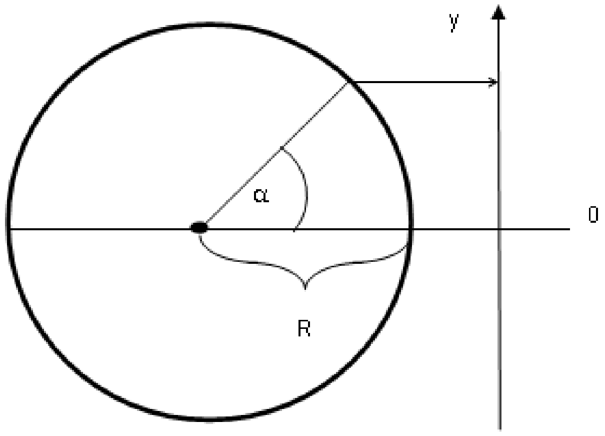

Fig. 7. Y-coordinate conversion scheme

$$y = \frac{R}{\sin\alpha} \qquad (1)$$

$$x = \frac{R}{\sin\beta} \qquad (2)$$

where: R - Equatorial radius (6378,245 m); α - geographic latitude [°]; β - geographic longitude [°].

Obtained coordinates (x, y) of this part of the circuit were loaded into a spreadsheet in order of getting a curve, which became a profile of the bend. Set of points was approximated following the principle: each point with neighbored point constitute together a circle, each next circle is tangent to the previous one. Additionally, smoothing function was used. It allowed to create a continuous and mild curve which was a guide for spreading surface of the circuit along it with Sweep function (Fig. 7). Average width of race track was assumpted as 21,7 m.

2.4 The Second Stage of Research: the Analysis of Vehicle Passage on Lavant Corner Model.

For the purposes of carrying out the simulation, CAD model of vehicle required few changes as well as parameters of simulation. It was necessary to define appropriate mathematic functions and conditional expressions responsible for controlling wheel turn angle depending on currently taken part of the bend.

As to perform simulation of passage, one more Revolute relation was added. It determines ability of wheels turning. Wheels turning function based on radiuses of circles from which curve was created and geometric relation between: turning radius, turning angle, wheelbase (Fig. 8, Eq. 1 and Table 1). These relations contributed to specifying turning radiuses for particular sections of bend. A vital assumption was that vehicle during taking the bend do not brake.

First simulation emerged that due to insufficient number of turning angle values, passage within borders of race track was impossible. Following data from GPS were collected after too long intervals of time. For the sharpest part of corner is needed greater density of input data for more smooth turning function. What is more, these calculated values don't cover phenomenon mentioned at the first stage of research. Despite the fact that this data could not be used for direct controlling the vehicle turn, it was possible to calculate a quadratic polynomial basing on them (Equations below). Application of the polynomial caused smoother turn and increase of stability at the sharpest part of the corner.

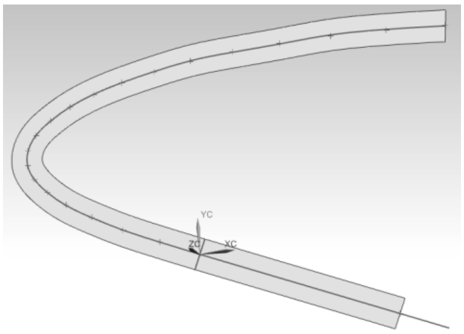

Fig. 8. The Lavant corner model

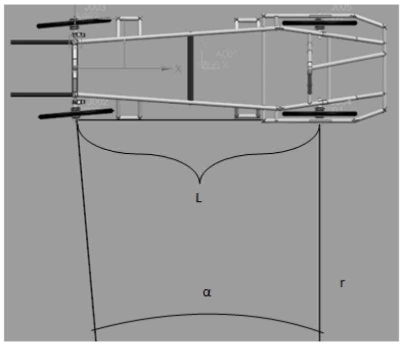

Fig. 9. Geometric relations

$$\alpha = arctan\frac{L}{r} \quad (3)$$

where: L – wheelbase [m], r - turning radius [m] and α - turning angle [°].

Tab. 1. Calculated turning angles

Radius r [m]	α [^{o}]
1134,42	0,068437
292,80	0,265143
79,54	0,975924
21,48	3,609476
42,61	1,821497
145,00	0,535414
304,94	0,254596
532,38	0,145827
853,47	0,090964
1761,01	0,044086

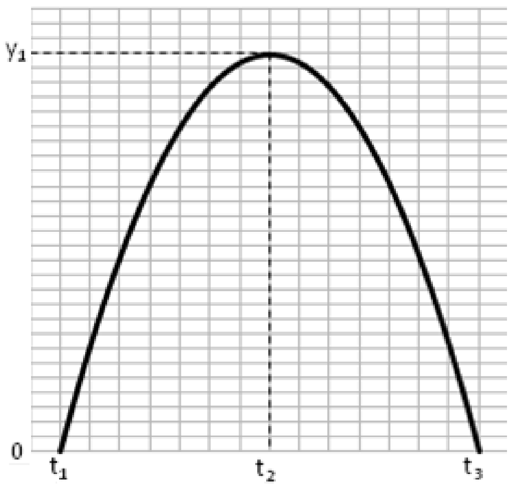

Fig. 10. Quadratic polynomial

$$f(t) = a \cdot (t - c)^2 + b \quad (4)$$

$$b = y_1 \quad (5)$$

$$a = \frac{0-b}{\left(\frac{t_3-t_1}{2}\right)^2} \quad (6)$$

$$c = t_2 = \frac{t_3+t_1}{2} \quad (7)$$

y_1 - turning angle magnitude [m],
t_1- turning start time [s],
t_2 - time of achieving turning angle magnitude [s],
t_3 – turning finish time [s].

By trial and error method, parameters of equation were modified: turning angle magnitude, turning start time, turning finish time. It was proceeded until the vehicle successfully travelled entire bend. This analysis took into consideration conclusions from the first stage of research.

Finally the function assumed form of:

$$f(t) = -0.2196 \cdot (t - 13.5)^2 + 2.69 \quad (8)$$

The function is active in strictly specified period of time. It starts its action after vehicle achieves sufficient velocity. That was realized with the use of conditional expression IF [1] offered by Function Editor for parameters of motion relations.

IF(IF(TIME-10: -1, 0, MAX(0,TIME-17)): 0,-0.22(TIME-13.5)*(TIME-13.5)+2.69,0)*

Driving torque had value of 40 Nm and was maintained for 8 s. After this time car hits the speed of 54 km/h and driving torque is turned off. This action is also executed with the use of IF expression.

IF(IF(TIME-1: -1, 0, MAX(0,TIME-8)): 40, 40, 0)

After finishing the corner, subsequent actions should focus on driving the car out on straight section of circuit. Due to time-consuming process connected with preparation of this function, at this stage of the research, simulation was limited to successful traveling entire bend (Fig. 9).

Further studies are going to bring up an issue of height of the race track (Z coordinate) and resistive forces (air resistance). These problems cannot be solved simply because of impossibility to insert data about them directly to simulation.

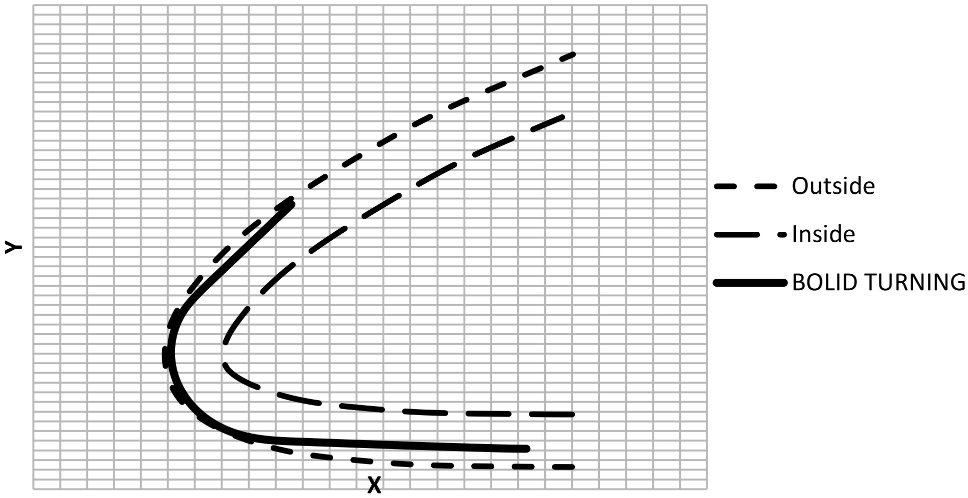

Fig. 11. Results of simulation

3. CONCLUSIONS

The issues, connected with the passage of Silesian Greenpower bolide, which were brought up in the article are significant in view of optimal track during the race as well as improving the construction of the described race car – its shape and distribution of its components' mass.
NX 8.5 program with its Motion Simulation module enables to prepare simulation which covers many factors [4]. They have major influence on a race car's passage. Phenomena which take place during bolide turning can also be observed. It means not only the movement of the vehicle, but also accurate data which can be exported into spreadsheet. The better computing capabilities of computer, the more accurate data can be obtained.
The accuracy of a simulation depends on many other factors too. Among them, the most important is the aspect of input data concentration (as in the case of discussed part of the track). The more data about the physical conditions of the passage, the greater potential for simulation realigning. For example, air resistance can be such an additional parameter. One more factor which is taken under consideration by the team can lead to victory.
The analysis of bolide understeering and oversteering [2] makes it possible to correct the construction and design of the car. Such research can lead to obtaining more favorable terms of the vehicle control and optimal passage parameters as well as those connected with key parts of the track.
The presented research is a pattern of that type of analysis. Such studies can help the team to modify the vehicle before next race as well as to select and carefully plan the optimal track for a driver. Physical parameters, various properties of the car and functions connected with the wheels turn or drive can be modified in Modeling and Motion Simulation modules. Firstly, these changes should be checked and compared with scheme calculations. Thereby, it is possible to find optimal set of output data which can be used by the team.

4. REFERENCES

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