Efficiency of the simulation model of a light commercial vehicle

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Abstract. The paper describes the results of the efficiency analysis of the simulation model of light commercial vehicle GAZ GAZelle NEXT. The efficiency of the model is confirmed by comparing the results of field test and calculation studies of controllability. The model is built in the MSC ADAMS/Car software package. It accounts for the mass-inertial characteristics of sprung and unsprung masses; the model of the suspension system simulates the kinematics and elasto-kinematics of the suspension and steering control, as well as elastic and damping elements. The tire model simulates vertical stiffness and damping, the slip stiffness depends on the vertical load, the longitudinal slip coefficient and the lateral angle of tire relative to the contact surface. The assessment was made by comparing the data obtained experimentally and by calculation. The test is conducted using the Fishhook method applied by NHTS for the vehicle stability analysis. The resulting errors are analyzed based on relative and absolute error values. When analyzing lateral acceleration and yaw rate deviations, the mathematical statistical tools are employed: average deviation, dispersion, root-mean-square deviation. The discrepancy between the results and the deviation of the average values does not exceed 10%. Minor deviations and scatter of results shows the efficiency of the simulation model and that this model can be employed for simulating the curvilinear motion of light commercial vehicles and assessment of their controllability and stability characteristics.

1. Introduction
The efficiency analysis of the model is required to assess the degree of similarity of the model [1]. The model efficiency can only be proved by experiment. For confirmation of the model efficiency the model reactions are assessed for consistency with the model object. The reactions are analyzed based on average responses values and dispersion of the response deviations. The model is characterized by the efficiency zone which is a set of situations when the model is efficient. The model accuracy is characterized by mismatch between relevant parameter of the model and the subject of study.

2. Object of study
The subject of research and modeling is GAZ GAZelle NEXT model A21R22 with a gross weight of 3500 kg, load on the front axle 1325 kg, load on rear axle – 2175 kg; curb weight 2040 kg. The vehicle is equipped with Cordiant Business tires 185/65R16C. It is designed with independent front suspension on double wishbones, independent rear suspension on semi-elliptical springs. The
suspension is equipped with telescopic oil shock absorbers and anti-roll bars. The transmission is mechanical with a five-speed gearbox. The vehicle features rear axle drive and open type differential.

The simulation of the motor vehicle is carried out in the object-oriented software package MSC ADAMS Car. The simulation model features the mobility in all 6 degrees of freedom. It takes into account mass-inertial characteristics of sprung and unsprung masses; the suspension model simulates the kinematics and elasto-kinematics of the suspension and steering control, as well as elastic and damping elements. The tire model is built on the basis of the H.B. Pacejka theory. It takes into consideration the vertical stiffness and damping, the slip stiffness depends on the vertical load, the longitudinal slip coefficient and the lateral angle of tire relative to the contact surface.

3. Experimental and theoretical research

The methodology and results of the vehicle field tests the under study are published in papers [2-9]. The controllability and reactions of the subject of interest is subjected to the Fishhook test used by NHTSA [10] for the dynamic rollover stability analysis of the vehicle. A steering robot is used for this test. The computer-aided analysis of the vehicle significantly improves the reliability and repeatability of results. The model efficiency assessment is based on results of one test run. The experimental research is conducted using measurement equipment of the ‘Transport Systems’ Shared Facilities Centre of NNSTU.

The following parameters were recorded during the tests: steering wheel angle, longitudinal vehicle speed, yaw rate, lateral and longitudinal acceleration, as well as the displacement of the center of gravity in the plane of the road. Overlay graphs are shown in the figures for the purpose of clarity when comparing field tests and calculation results. The field tests and simulation results were overlaid within the time domain with reference to the common starting point of the steering wheel rotation. Relative and absolute deviations were used for the model efficiency analysis. The average deviation relative of the calculation results vs the experiment was computed by formula 1.

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} \frac{x_{\text{experiment}}^i - x_{\text{simulation}}^i}{x_{\text{experiment}}^i}$$  \hspace{1cm} (1)

Figure 1 shows the steering wheel angle curves during the experiment and simulation. The model employed the dependence of the steering wheel angle on field test results, therefore the graphs coincide.

![Figure 1. Steering wheel angle](image)

The speed of motion exerts rather strong influence on how the vehicle reaction to the steering wheel. Figure 2 shows the graphs of longitudinal motion speed during the test and simulation.
The average deviation of the longitudinal motion speed of the model is 1.6 km/h. The maximum motion speed deviation is 3.87 km/h. The average relative deviation of the model speed is 3%, but not exceeding 6%.

Figure 3 shows the yaw rate graph. The yaw rate is one of the important indicators for the vehicle controllability analysis.

The average relative deviation of yaw rate is 6%. The yaw rate deviation during the simulation and testing is not constant and can be represented as distribution of yaw rates as shown in Figure 4. It is evident from the histogram that the distribution of the yaw rates is normal. The absolute average deviation of yaw rates is -1.0234 deg/s. The dispersion of yaw rate deviation is D=4.464 mm²/s⁴, root-mean-square deviation is σ=2.11mm/s². The maximum yaw rate deviation is 7.05 deg/s.

![Figure 2. Longitudinal travel speed](image1)

![Figure 3. Yaw rate](image2)
Figure 5 shows the lateral acceleration graphs.

Average relative deviation of lateral acceleration 7%. The difference in lateral accelerations can be represented as a distribution of lateral accelerations as shown in Figure 6. The average deviation of lateral accelerations 391.92 mm/s². Dispersion of lateral acceleration deviations is $D=2483002$ mm²/s⁴, root-mean-square deviation $\sigma = 1575.7$ mm/s². Maximum lateral acceleration deviation is 5814 mm/s².
Since the investigations were conducted in different coordinate systems, for trajectory error calculation some transformations and alignment of the trajectories are required. For the purpose of alignment, the trajectories were shifted and turned in such a way that initial conditions of motion would coincide. The straight-line motion of the vehicle at the beginning of the test is taken as the common axis, while the common point of the trajectories is determined by the time when the steering wheel starts turning. Overlaid trajectories of the vehicle center of gravity, field studies and simulation modeling are shown in Figure 7.

The difference in trajectories is the distance between the center of gravity position of the model and that of a vehicle in the physical world during the test, at the same point in time that is calculated by formula (2).

$$\Delta t = \sqrt{(X_{simulation}^t - X_{experiment}^t)^2 + (Y_{simulation}^t - Y_{experiment}^t)^2}$$ (2)

The variation of the distance between the centers of gravity relative to the time of the vehicle maneuver is shown in the form of a graph in Figure 8.
Figure 8. Trajectory deviation

The maximum deviation of the trajectories at the end of the test was 3.24 m, with the total distance traveled 106.93 m. The relative trajectory deviation from the path is 3%.

Conclusions
The efficiency of the simulation mathematical model was analyzed by comparing the results of a full-scale experiment with the simulation results. The efficiency and accuracy analysis of the model was based on the Fish Hook test results. The model efficiency was assessed by the parameters characterizing controllability and stability of the vehicle motion: longitudinal speed, yaw rate, lateral acceleration, trajectory of motion. The comparison of the experiment and simulation modeling results proves the model efficiency. The discrepancy between the results and the deviation of average values does not exceed 10%. The absolute deviation of the longitudinal speed of motion does not exceed -6%, that of the trajectory – 3%. The average deviation of lateral acceleration is 7%, yaw rate - 6%. The average yaw rate deviation is -1.0234 deg/s, that of lateral acceleration – 391.92 mm/s². The standard deviation of yaw rate is 2.11 mm/s², that of lateral acceleration – 1575.7 mm/s². Minor deviations and scatter of results shows the efficiency of the simulation model, and that this model can be employed for simulating the curvilinear motion of light commercial vehicles and assessing their controllability and stability characteristics.

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