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EVALUATION METHODOLOGY OF DESIGN PARAMETERS INFLUENCE TO THE BRAKING PROCESS OF PASSENGER CAR-TRAILER COMBINATION

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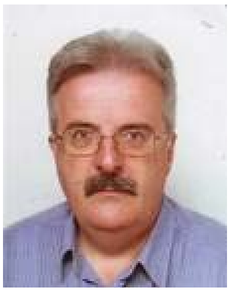


ABSTRACT

In contemporary traffic, the need of movement for various forms of engagement between the passenger vehicle and the trailer becomes more intensive and emphasized. In certain conditions, in this engagement it may come to non-conformity in relation to the acceleration and braking characteristics of the combination because of design reasons.

Therefore, efforts are made to achieve optimal braking performance, steering characteristics and stability through design measures and other engagement constrains of the vehicle combination.

Considering the aforementioned, it all started from the suitability to determine the evaluation methodology on the impact of certain design factors to the passenger vehicle - trailer combination behavior in the braking process.

KEYWORDS

combination, design factors, methodology, braking

INTRODUCTION

Behavior specifics of the vehicle combinations in traffic largely depend on the dynamic interaction between the vehicle and the trailer, which is conditioned by the design adaptation, operation conditions, traffic state and also by the driver qualifications for handling such combination. The design non-conformity of the combination that appears in operation is also expressed by the various forms of engagement of the vehicle with freight trailer, with caravan and other types of special trailers intended for transport of boats, bees, animals, etc. In such engagement, in certain conditions non-conformity of longitudinal - dynamic performance and braking characteristics can appear, from where certain problems arise with the steering and stability characteristics. In the vehicle combination, it is logical to have an interaction between the towing-vehicle and the trailer that reflects on the proper functioning of the combination as a whole.

Because of the previously stated, and starting from the statistical indicators which explain that number of the trailers intended for passenger vehicles each year is progressively growing, optimal longitudinal - dynamic performance and braking characteristics should be achieved, as well as optimal steering and stability characteristic by design measures. These kinds of solutions would reduce the driver involvement in the steering of the vehicle combination that would contribute to bringing traffic safety to a higher level.

Research object

According to the stated findings, the main purpose of this research is - by using modern scientific methods in the field of: modeling, simulation, optimization and experimental verification - to determine the evaluation methodology on the impact of certain design factors to the passenger vehicle - trailer combination behavior in the braking process.

Research methodology

The research methodology of this paper covers:

- Carrying out theoretical considerations about the impact of certain design factors of the vehicles and their trailers to the combination behavior in braking conditions;
- Carrying out analyses of the adequacy (suitability) for acceptance of certain software packages by which modeling of the towing vehicle with a trailer will be performed, as well as a simulation of the combination behavior with changes of the influential design factors in actual and specific operation conditions during braking;
- Performing analytical simulations and their comparison with the simulations obtained by ADAMS;
- Conducting experimental research and comparative analyses of the obtained results with the results from the simulations in order to get evaluation about the level of their match;
- Conclusions regarding the verifications of the evaluation methodology on the impact of design factors to the combination in the braking process.

Vehicle design factors affecting the combination behavior in braking process

Based on the theoretical research of the braking process of the combination between the passenger motor vehicle and the trailer [1, 2, 3, 4, 19, 20, 21], it comes to the conclusion that the design factors that directly affect and disrupt the process of braking are:

The mass and the position of the center of gravity on the vehicle and the trailer, and its material moments of inertia, wheelbases, wheel track, position of the coupling point between the vehicles, design characteristics of the trailer braking system, built-in stabilization device of the vehicle (ESP), and many more.

Because of the complexity of the issue, focused vehicle modeling was carried out for the paper towards the research goal. In that way, the complex dynamic system was simplified but the structure of the connection and mutuality of the elements was taken into account. Thus, systems that can be mathematically modeled in a simpler manner are obtained and by practical verification and simulation, validation of the results is performed with minimal costs.

An example of the elements important to simplifying the construction of the model for the braking behavior of the vehicle, during the planned braking in certain direction of good road surfaces is introduced that the vehicle during the braking process continues to move without skidding and meandering. Therefore the appearance of gyroscopic effects on the wheels is neglected. Also when simple modeling, it is commonly considered that the value change of the normal reactions in the braking process does not affect the value of the longitude coordinates of the center of gravity, respectively it is taken that during the whole braking process l_p, l_z and h_c are constants, etc.

Pursuant to the introduced simplification, a simple planer model is obtained which could be interpreting simply analytical. Simulations in global range are in accordance with the values obtained in real vehicle test.

Modeling of the combination

The application of numerical methods as a basis for computer simulation enables dynamic modeling of complex systems [1]. In the past period for modeling of complex dynamic systems and performing parametric simulations, numerous user-oriented computer programs were created such as MATLAB, MATRIX, SIMULINK, etc.

The programming package ADAMS (Automatic Dynamic Analysis of Mechanical Systems) in the last few years has been developed to the extent of forming several separate program modules for different needs. ADAMS/CAR is a specially designed environment for modeling vehicles that allows the creation of virtual vehicle prototypes and their subsystems, and also allows their analysis as it would be done on physical vehicle prototypes [1, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18].

The model developed in the program package ADAMS/CAR presents a combination of a passenger motor vehicle with a trailer. The first phase of building the model is performed by creating new templates for certain vehicles as well as by adaptation of the existing templates in terms of their dimensions and characteristics. In the second phase template assembling in one system is done that has the test possibility i.e. simulated motion of the vehicle in different situations and analysis of its behavior.

For creating the towing drawbar, a template was built that contains the device information (figure 1). By defining three points in space and by building a constructional frame, the device is determined by location and by direction in a coordinate system which corresponds to other templates.

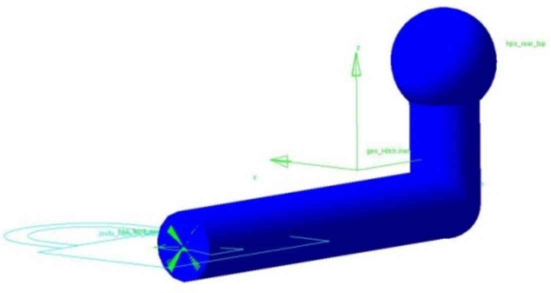


Figure 1

Using the ADAMS/CAR possibility for building assemblies and with the use of the already created templates, assembly is made. In this way, a vehicle with characteristics same as those on the physical model is obtained (figure 2).

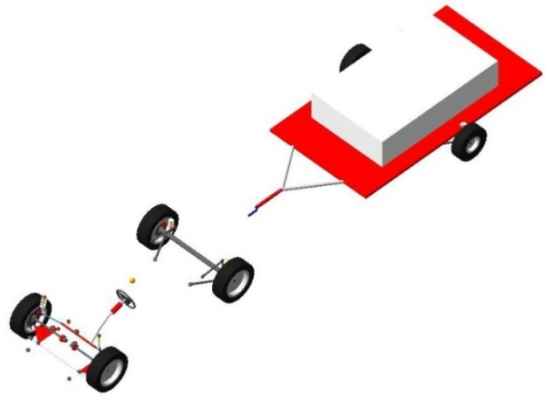


Figure 2

Analytical verification of the model

Verification of the designed model in ADAMS/CAR was performed by making an analytical program (model) which on the basic level enables obtaining outputs from the simulation for the engagement by changing the design factors.

Figure 3 shows the scheme for the analytical position of the engagement while braking in a curve. Figure 4 shows the analytical model verification program.

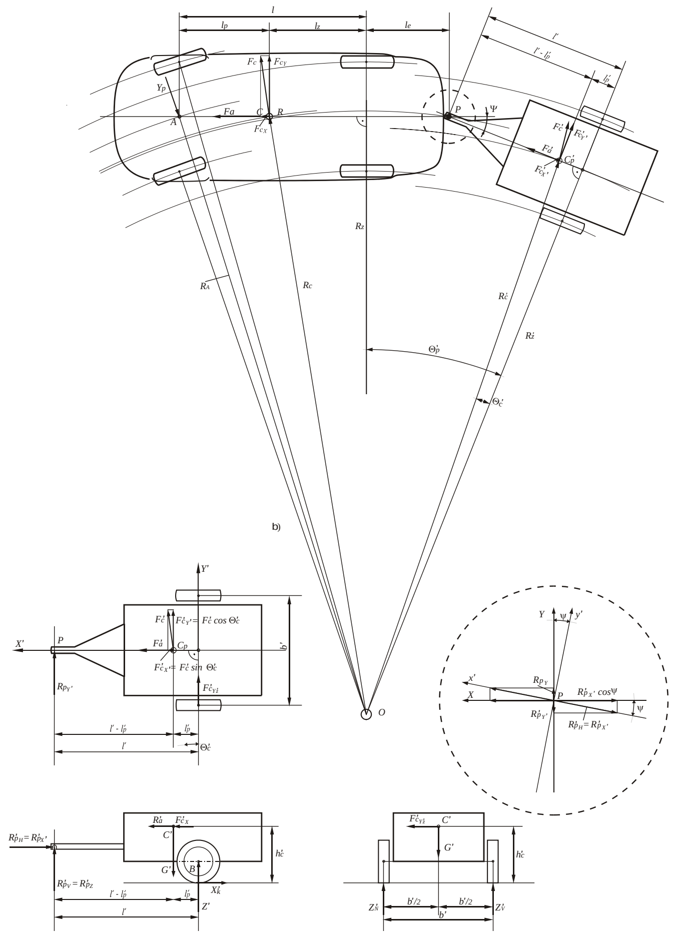


Figure 3

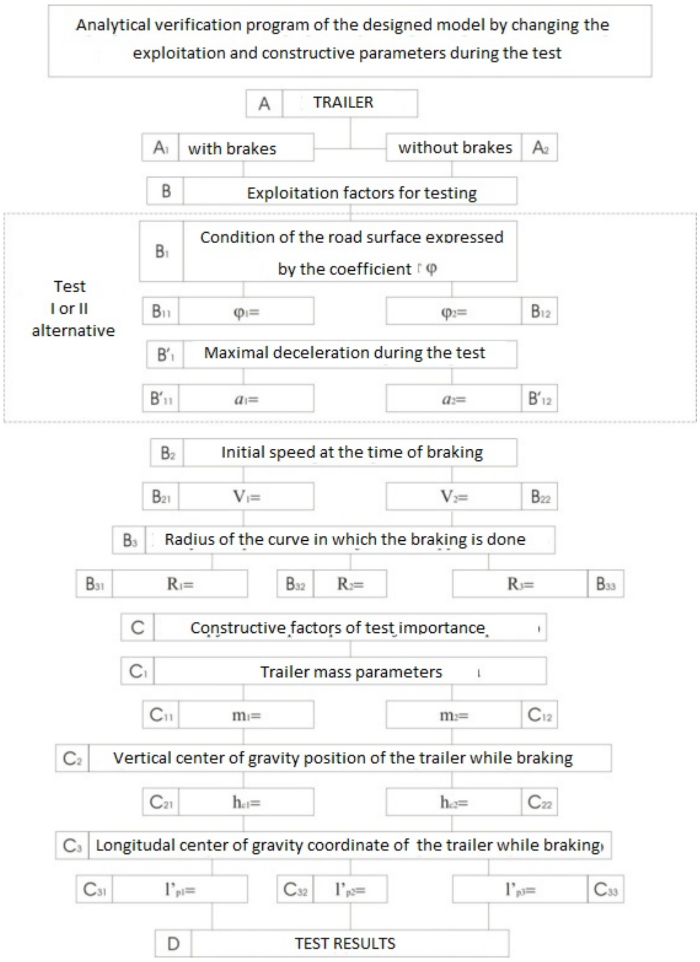


Figure 4

Because of the different nature of the designed model in ADAMS/CAR and the analytical model, the results obtained at identical test conditions are given in Table 1.

As an example in Table 1 only the results of the values from the braking reaction of the automobile and from a non-braked trailer while braking in a curve are shown. The test is performed while braking with the combination of an initial speed of 50.40 [km/h] on a regulated road surface with $\varphi = 1$, in a curve with a radius R=50 [m].

Table 1

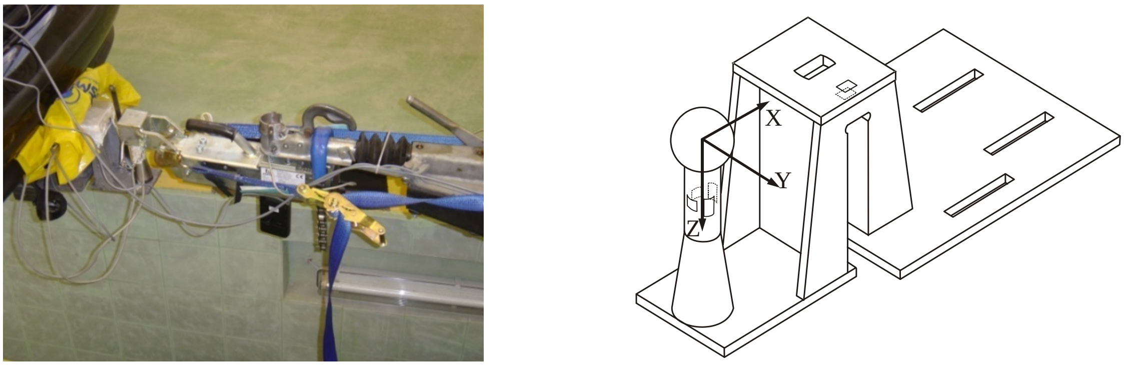
Parameter [N]	Mark	ADAMS	Analytical	Difference [%]
Front axle-left wheel	Zpl	3.715,0	3.955,67	6,47
Front axle-right wheel	Zpd	5.232,9	4.976,95	4,89
Sum of the front axle	ΣZp	8.942,9	8.932,62	0,11
Rear axle-left wheel	Zzl	1.457,8	1.390,08	4,64
Rear axle-right wheel	Zzd	2.870,7	3.019,25	5,17
Sum of the rear axle	ΣZz	4.328,5	4.409,33	1,86

Trailer axle-left wheel	Z'l	3.346,6	3.172,5	5,20
Trailer axle-right wheel	Z'd	3.950,6	4.012,68	1,57
Sum of the trailer axle	ΣZ'	7.297,2	7.185,16	1,53
Forces in the drawbar	X	3.197,8	3.153,5	1,38
	Y	979,6	929,17	5,14
	Z	390,5	491,84	25,95

According to the performed extensive analytical simulations covered with the program of Figure 4, as well as by the compared simulations in ADAMS/CAR about identical conditions, it is concluded that there is a high degree of mutual compliance.

Experimental verification of the model

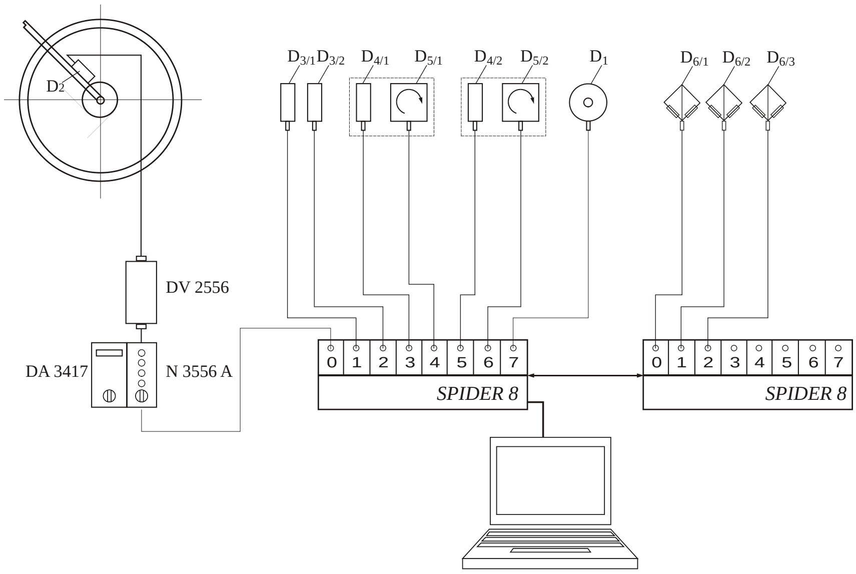
Experimental verification of the designed model in ADAMS/CAR was performed on the basis of specially developed methodology that allows direct experimentation with real vehicle and trailer engaged in the combination. The base of the installation is presented by the force measurement system i.e. X, Y and Z – reactions in the coupling point of the vehicle (Figure 5a), normal accelerations during braking in a curve as well as deceleration of the engagement in the motion direction. To determine the X, Y and Z reactions in the drawbar ball, a special device with strain gages has been designed and built. The X and Y reaction are measured indirectly by measuring the deformations on the neck of the ball (Figure 5b).



a b

Figure 5

Figure 6 shows a schematic view of the complexity of the measurement system with which the tests are performed, while Figure 7 gives a schematic view of the experimental test program for verification of ADAMS/CAR model.



D_1 – linear potentiometer type
D_2 – magnetic transducer HBM type MA1
$D_{3/1}$ и $D_{3/2}$ - acceleration transducer HBM type B12/200
$D_{4/1}$ и $D_{4/2}$ – acceleration transducer type BOSCH – DRS-MM1 OR
$D_{5/1}$ и $D_{5/2}$ – transducer for angular velocity BOSCH – DRS-MM1 OR
$D_{6/1}$; $D_{6/1}$ и $D_{6/3}$ – strain gage resistive transducers for force measurement type HBM LX21
S_1 и S_2 - data acquisition systems HBM type SPIDER – 8
S_3 и S_4 – data acquisition systems type DV2556 and N3556A
C - computer

Figure 6

A: Vehicle type

A_1: Single vehicle | A_2: combination with braked trailer | A_3: combination with non-braked trailer

B: Loading of the trailer

B_1: Empty trailer | B_2: trailer with TICO | B_3: trailer with PUNTO

C: Braking trajectory

C_1: Braking in direction | C_2: Braking in left curve | C_3: Braking in right curve

D: Braking intensity

D_1:a_x=a_1 | D_2:a_x=a_2 | D_3:a_x=a_3

Figure 7

In compliance with the possibilities provided by the measuring equipment and signal acquisition, the obtained results are of high quality for further processing. Table 2 gives a comparison example of the reactions obtained by experimental tests and by simulation of the combination, during braking in a given direction with a non-braked trailer for the same tests.

Table 2

Measuring parameter	Dimension	Simulation		**(4-3)/3** * 100 [%]
		ADAMS / CAR	Experiment	
1	**2**	**3**	**4**	**5**
Z_{pls}	[N]	3.650,8	3.561,0	2,4
Z_{pds}	[N]	3.624,2	3.610,0	0,3
Z_{ps}	[N]	7.275,0	7.171,0	1,4
Z_{zls}	[N]	3.098,4	3.041,1	1,8
Z_{zds}	[N]	3.089,3	3.217,7	4,1
Z_{zs}	[N]	6.187,7	6.258,8	1,1
$Z_{ps}+Z_{zs}$	[N]	13.462,7	13.429,8	0,2
Z'_{ls}	[N]	2.195,5	2.207,2	0,5
Z'_{ds}	[N]	2.196,2	2.187,6	0,4
$Z'_{ls}+Z'_{ds}$	[N]	4.391,7	4.394,8	0,1
ΣZ	[N]	17.854,4	17.824,6	0,1

Table 3 gives the X and Z reactions in the drawbar ball of the combination with a non-braked trailer while Table 4 gives the same results for the combination with a braked trailer.

Table 3

Measuring parameter	Dimension	Simulation		**(4-3)/3** * 100 [%]
		ADAMS / CAR	Experiment	
1	**2**	**3**	**4**	**5**
a_x	[m/s^2]	2,94	2,90	1,3
X	[N]	1.406,0	1.288,0	8,3
Z	[N]	168,0	141,0	16,0
Z_o (V=0)	[N]	192,0	195,0	1,5

Table 4

Measuring parameter	Dimension	Simulation		**(4-3)/3** * 100 [%]
		ADAMS / CAR	Experiment	
1	**2**	**3**	**4**	**5**
a_x	[m/s^2]	5,79	5,60	3,2
X	[N]	222,7	248,0	11,2
Z	[N]	496,6	567,0	14,0
Z_o (V=0)	[N]	197,0	202,0	2,5

From the performed comparisons of the results shown, the experimental tests and the ADAMS/CAR simulations, a high degree of matching is found. This means that the designed model of the combination automobile - trailer fully fits the assignation and can be used as an analysis and evaluation tool of the influential design factors on its behavior in real and specific conditions while braking.

CONCLUSIONS

By the studies covered in this paper and the conducted analyses, it is concluded that the achieved high degree of matching in the results obtained with the ADAMS/CAR designed model with its analytical results and the results of experimental verification is the outcome of the applied methodology.

Based on the verification of the methodological approach for modeling the combination engagement in ADAMS/CAR, a powerful tool has been obtained, which provides simulations of the combination behavior under the influence of certain design factors. It is not only for braking conditions, but in general for the simulation of any process which could be of interest, especially in the area of performance evaluation of the combination steering and stability.

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