SAFETY AND ANALYSIS OF MODERN TRANSPORT ARTICULATED VEHICLES MOTORIC PROPERTIES

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Abstract

The paper presents main causes of threats posed on articulated vehicles traffic safety and the methods for their prevention. Based on the motoric properties evaluation method, the capabilities of military articulated vehicles as of 2010 were examined in that respect. Articulated vehicles, which include truck-tractor and semi-trailer, are used for carriage of the so-called combat technology in the armed forces. Problems related to transportation of military equipment have inter alia been presented in papers [1, 2]. They result primarily from the significant linear dimensions and large weights, which are characteristic for the articulated vehicle of truck-tractor and semi-trailer. Other, additional problems affecting the safety of traffic are related to the type of cargo and its fixing mode [3]. In the case of articulated military vehicles, in most cases, wheeled or tracked vehicles are transported, that is a very specific cargo, difficult to be fixed to the flatbeds of the semi-trailers. All these vehicles should have their load floor located as low as possible because the floor placed too high may cause that the total height of the vehicle and the load carried will interfere with the road infrastructure (tunnels, overpasses, electric traction over the roadway, etc.), and the highly located centre of mass negatively affects the stability of motion [3].

Keywords: *safety, tests, articulated vehicles, tanks transportation*

1. Causes of accidents and safety improvement opportunities

When reviewing methods for improving the stability of road articulated vehicles, i.e. truck-tractor - semi-trailer, the main threats posed on the stability of road combined vehicle are worth mentioning, that is, the small margin of stability maintenance, especially at higher velocities compared to a single vehicle. It is worth emphasizing that the behaviour of articulated vehicles, namely: the truck-tractors with semi-trailers strongly depend on the running gear configuration, cargo, and pavement condition [4]. Another cause of accidents is the jackknifing of the semi-trailer as a result of uneven lateral forces, or their disappearance in the contact area of wheel tires of truck-tractor's rear axles and/or the semi-trailer's wheels heavy braking. Another reason for the loss of stability is the serpentine movement of the semi-trailer as a result of transverse oscillations, caused by air resistance or movements of the steering wheel. The safety is also affected by a response time of the semi-trailer to a forcing signal arising from the steering system of the truck-tractor, which is related to a distance between the truck-tractor and the semi-trailer. Significant is also the interaction in the form of the feedback signals received by a driver and originating from the semi-trailer systems (braking, steering, running gear) [4].

A difference in the maximum value of the lateral acceleration that occurs between the truck-tractor and the semi-trailer in the middle of the lane-change manoeuvre is a negative factor that affects the number of accidents involving articulated vehicles. It is defined by Reward Amplification (RWA) ratio.

Improvement of the traffic safety of road articulated vehicles, i.e. truck-tractor and semi-trailer is a complex issue. In order to eliminate hazards for articulated vehicles, analyses [5, 6] are carried out of the semi-trailer rollover and a safe boundary height of the centre of mass is determined. The calculation results are sometimes [6] supported by numerical and experimental studies.

Tests of the articulated vehicles dynamics, namely: the truck-tractor and semi-trailer as well as their stability, focus both on the analysis of classical linear models, mostly with three degrees of freedom, and also on simulation studies performed on the basis of nonlinear models that take into account the dynamics of the tires and suspension. As a method to control the truck-tractor and semi-trailer articulated vehicle stability, it is proposed to control the thrust angle by reducing the rotating torque arising between the truck-tractor and the semi-trailer by proper distribution of braking forces between the wheels on each side of the semi-trailer. A stability control system for the truck-tractor and semi-trailer articulated vehicle [7, 8], based inter alia on active suspension, is being developed.

A comprehensive overview of methods for improving the stability of the truck-tractor and semi-trailer articulated vehicle is described in paper [4]. They include the Direct Yaw Control (DYC) method that involves monitoring of the yaw angle and, if necessary, generating the stabilising torque by braking relevant wheels of the articulated vehicle, using ABS. Some methods are based on the rear wheel steering (RWS). The purpose of the semi-trailer rear wheels steering is to minimize the difference in the lateral acceleration between the truck-tractor and the semi-trailer as well as the semi-trailers rollover (the RWA ratio described earlier). Realization of the semi-trailer wheels steering algorithm may be carried out on an open loop when the turn angle depends on the truck-tractor wheels turn and the driving velocity. For optimum RWS control, also the wheels slip is taken into account as well as a coupler position against the longitudinal axis of the semi-trailer. Experimental studies are in progress concerning the assessment of articulated vehicles behaviour in the curvilinear motion with the load [9].

There is a noticeable significant advantage of experimental studies over the simulation works, which first of all effects from a difficult in its description complex object and the occurring phenomena.

A possibility of smooth and dynamic driving on public roads, with a large weight of the objects carried, positively affects the traffic safety level. Assessment of the vehicles motoric properties is justified in this case. This may be conducted following the method developed at the Military Institute of Armour and Automotive Technology (WITPiS) [12].

2. Method for assessment of articulated vehicles motoric properties [12]

A method for matching the required technical characteristics involves their specification and definition of quantitative characteristics, which allows for professional evaluation of commercial offers and for a decision to be taken by the equipment manager.

The basic characteristics include as follows:

- load capacity;
- maximum velocity and road slope at V_{max};
- running gear of the truck-tractor and semi-trailer;
- leverages on axles of truck-tractor and the semi-trailer;
- tire characteristics;
- motion stability;
- U-turn diameter;
- cab characteristics and ergonomic conditions;
- ballistic protection and against mines.

The basic criterion for assessing motoric properties is an ability of the articulated vehicle at maximum velocity on good roads, with slopes of 1% - 2%. Following this criterion, nominal power of the engine is selected for an articulated vehicle of a given weight.

Computational formula for the total unit power demand and partial powers depending on the velocity has the form:

$$N_j = \underbrace{\frac{3.7 \cdot f}{\eta_m} \cdot V}_{\frac{N_f}{G}} + \underbrace{\frac{1.78 \cdot 10^{-5}}{\eta_m} \cdot C_x \cdot \frac{F}{G} \cdot V^3}_{\frac{N_p}{G}} + \underbrace{\frac{3.7 \cdot 10^{-2} \cdot p}{\eta_m} \cdot V}_{\frac{N_w}{G}}, \qquad (1)$$

where: η_m - efficiency of the power transmission system, based on [7], [6] = 0.85,
f - rolling resistance coefficient, based on [7] = 0.012,
C_x - air-flow resistance coefficient, based on [7]= 0.8,
P - road slope in %,
G - weight of articulated vehicle,
V - velocity in km/h,
$\frac{N_f}{G}$ - required unit power to overcome air-flow rolling resistance,
$\frac{N_p}{G}$ - unit power of air-flow resistance,
$\frac{N_w}{G}$ - unit power of road slope resistance.

3. Analysis and assessment of modern articulated vehicles motoric properties

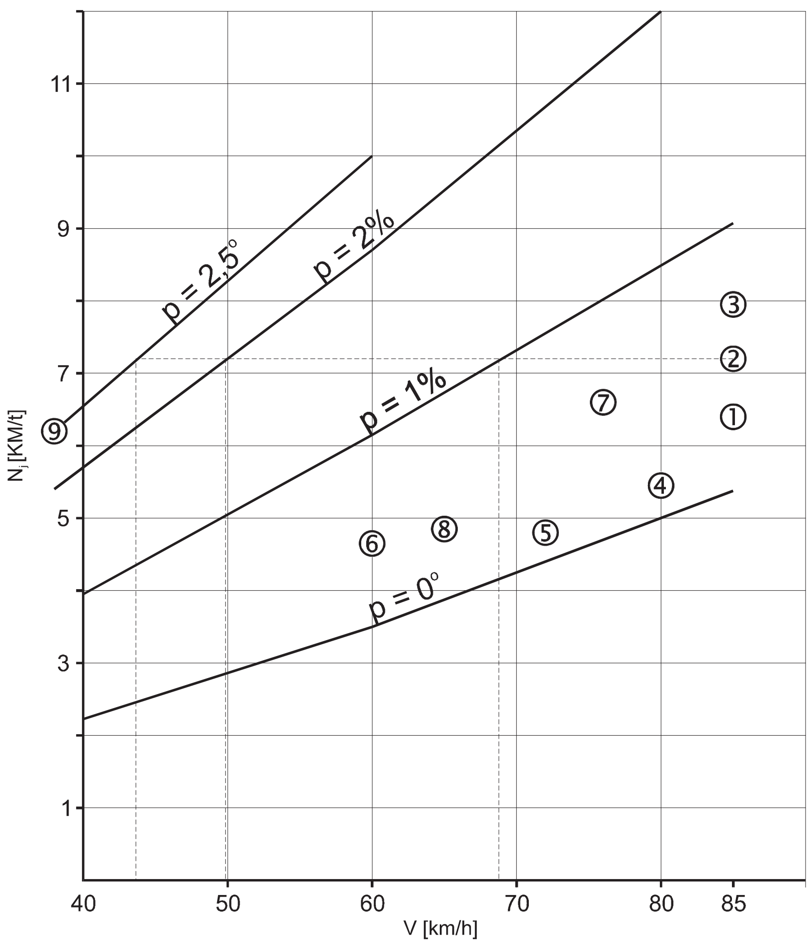
Table No.1 includes basic data [15] related to the currently operating truck-tractors. The newest flatbed vehicles designed for transportation of tanks have been taken into consideration.

Tab. 1. Characteristics of Truck-Tractors for Transportation of Tanks and Heavy Equipment

No.	Type, Running Gear, Country	Gross Combined Weight of Articulated Vehicle GCW / Weight Capacity	Max. Velocity	Engine Power / Unit Power	Truck-Tractor Curb Weight	Weight on Saddle / Weight on Truck-Tractor's running gear (GVW)	Size of Tractor Wheels
		T	km/h	KW (hp) / KW/t (hp/t)	t	t	
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	Tatra T816 8×8 Czech Republic	115 / 74	85	610(830) / 5.3(7.2)	20.5	23 / 43.5	front 16.00 R 20 rear 24 R 20.5 or 24 R 21
2	Unipower M 8×8 United Kingdom	115 / 75	80,0	515(700) / 4.5(6.1)	no data	*b.d.* / 47.4	24 R 20.5
3	Faun SL-T 50-2 8×8 Germany	92 / 52	63,5	537(730) / 5.8(7.9)	23	18.3 / 41.3	18.00 × 22.5
4	RenaultTRM 70 0-100 6×6 France	106 / 72	76	515(700) / 4.9(6.6)	14	25 / 39	385/95
5	Steyr 40 M 6×6 Austria	110 / 72	85	441(600) / 4.0(5.45)	17.5	21 / 38	24R 21

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
6	Volvo FL 12 H 6×6 Sweden	$\frac{90}{60}$	68	$\frac{309(420)}{3.4(4.7)}$	9.9	$\frac{23.6}{33.5}$	13 R 22.5
7	MAN HX 81 8x8 Germany	$\frac{150}{98}$	88	$\frac{500(680)}{3.3(4.5)}$	15	$\frac{32}{b.d}$	16.00 R20
8	Oshkosh M1070HET 8×8 USA	115	72	$\frac{441(600)}{4.0(5.45)}$	18.6	$\frac{20.4}{39}$	16.00 R 20
9	Iveco Traker/EuroTrak ker 6×6 Italy	$\frac{110}{75}$	85	$\frac{588(800)}{5.3(7.3)}$	17	$\frac{25}{42}$	24R21
10	Mercedes Benz 4850 A 8×8 Germany	$\frac{110}{73}$	90	$\frac{368(500)}{3.3(4.5)}$	17.2	$\frac{31}{48.2}$	14.00 × 20 or 24 × 21 R
11	MAZ 7428 8×8 Russia	$\frac{95}{70}$	65	$\frac{478(650)}{5(6.8)}$	27	$\frac{25.2}{46.8}$	18.00 × 24

The calculated dependencies of the required unit power output N_j on the motion velocity V, for road slopes of 0%, 1%, 2% 3%, on flat good roads, are illustrate in Fig.1. This figure includes N_j and V_{max} coordinates for a number of articulated vehicles, which are on stock of various armed forces.



1. Alvis Unipower, 8x8,
N_s = 750 hp,
m_c = 117, V = 85 km/h
2. Tatra T816, 8x8, 1R,
N_s = 830 hp,
m_c = 115,V = 85 km/h
3. Faun, 8x8, N_s = 730 hp,
m_c = 92,V = 85 km/h
4. Alvis Unipower, 6x6,
N_s = 600 hp,
m_c = 110, V = 80 km/h
5. Oshkosh M1070, 8x8,
N_s = 500 hp,
m_c = 104, V = 72 km/h
6. Volvo FL12H, 6x6,
N_s = 420 hp,
m_c = 90, V = 60 km/h
7. Renault TRM 700-100, 6x6,
N_s = 700 hp,
m_c = 106, V = 76 km/h
8. Iveco 320-45, 6x6,
N_s = 450 hp,
m_c = 93, V = 65 km/h
9. Alvis Unipower, 8x8,
at V = 38 km/h, p = 2.5%

Fig. 1. Dependence of the Required Unit Power N_j (KM/t) on Velocity V, at Road Slopes of 0%, 1%, 2%, 2.5%

Fig. 2 graphically presents the required powers of engines for tanks transporters at total weights of 90 t and 115 t, motion maximum velocities of 60 km/h and 80 km/h and road slopes: 0%, 0.5% and 1%.

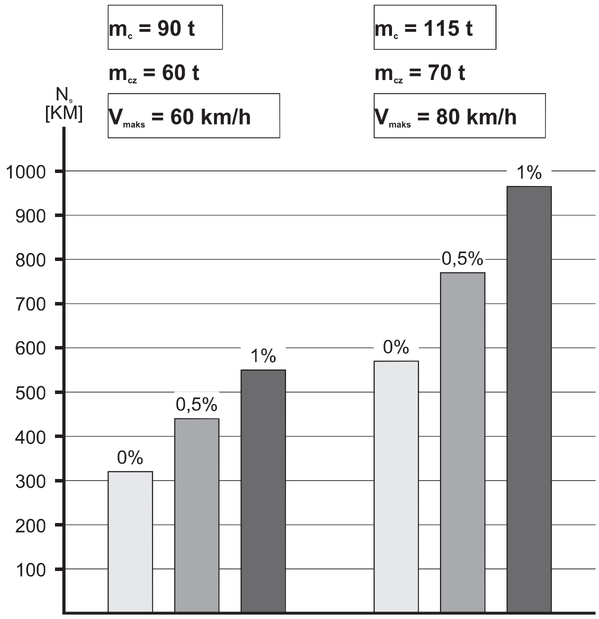
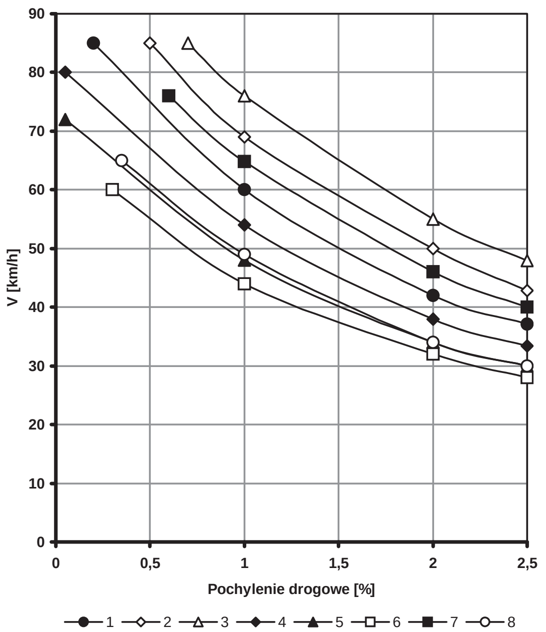


Fig. 2. Required Powers of Engines for Tanks Transporters at Total Weights of 90 t and 115 t, Maximum Velocities of 60 km/h and 80 km/h and Road Slopes of: 0%, 0.5%, 1%

In this figure, transporters have been conventionally divided into 2 groups of: older and younger generation:

- older generation for tanks of less than 60 tons of weight, and of the articulated vehicle weight up to ca. 90 tons, capable of a maximum velocity at ca. 60 km/h, at slopes of ca. 0.5% with engines power of 450 hp - 550 KM;
- younger generation with engines power of 700 hp - 850 hp, capable of transporting tanks and heavy equipment with weight of ca. 70 t, at total weights of ca. 110 - 115 t, with velocities of ca. 80 km/h, and at slopes of 0.5%.



1) *Alvis Unipower, 8x8*
2) *Tatra T816, 8x8, 1R*
3) *Faun, 8x8*
4) *Alvis Unipower, 6x6*
5) *Oshkosh M1070, 8x8*
6) *Volvo FL12H, 6x6*
7) *Renault TRM 700-100, 6x6*
8) *Iveco 320-45, 6x6*

Fig. 3. Dependence of the Articulated Vehicle Motion Velocity on Road Slope

Motion velocity of the articulated vehicle has been determined from the diagram in Fig. 1 in the following way: from point [N_j; V], a horizontal line was drawn for a defined vehicle to intersect with the curves for 1%, 2%, 2.5%. The point of intersection corresponds to the desired velocity. The procedure is shown in the example of point 2.

The results are shown in Figure 3.

Fig. 1 indicated that the hereto analysed articulated vehicles of both „older" and „younger" generation freely move only on flat roads with slopes close to 0%. This is the reason why the slopes of 1% - 2% that occur on flat roads must be driven at lower gears and obviously with much lower velocities. For the articulated vehicles analysed here the motion velocity at defined slopes differ considerably. This is illustrated by Table 2.

Tab. 2. „Older" and „Younger" Generation Transporters Motion Velocity on Slopes

Road Slope in %	Motion Velocity in km/h of Articulated Vehicles:		Percentage growth in velocity of „younger" compared to "older" articulated vehicles
	„older generation"	„younger generation"	
1	46 - 48	60 - 76	30 - 58
2	33 - 34	43 - 55	30 -61
2.5	28 - 30	38 - 49	35 - 63

The data included in the table refers to the movement at full power at nominal engine rotations. In practice, we rarely move at such rotations and therefore the velocities that provided in the table are reduced further on.

4. Summary

Data related to risks of the wheeled military vehicles motion and the methods to improve their safety indicate a proper research procedure. A solution of the primary problem of the wheeled military vehicles safety improvement should be based on an assessment of the impact of structural design changes, introduced into those vehicles, for their traffic safety. The basis for determining any changes in the level of traffic safety should be primarily the evaluation of research results for representative manoeuvres. Effect, however should be the introduction of modifications to the vehicle structure on this basis. This confirms that the assumed scientific target is valid, that is, to develop a methodology for determining the impact of selected structural changes on the military wheeled vehicles traffic safety.

A house or commercial computer software, made on the basis experimentally developed and verified mathematical models of motion and dynamics of two-and-multi-axis vehicles, can become the basis for the implementation of the scope of the simulation research studies. It is important to have adequate measuring facilities and qualified staff to carry out experimental research studies.

A modern, prospective transportation articulated vehicle should be capable of transporting tanks weighing up to about 70 tons at maximum velocities of about 80 km/h. In actual practice, operational transporters cannot permanently move on flat roads with no slopes at velocities corresponding to maximum engine revolutions. Rotational speeds should range between the maximum torque rotations and the rotations that are close to maximum ones. For the newer generation of transporters, the velocity will vary between 50 - 75 km/h, while for the older generation transporters the velocities range between 40 - 55 km/h. This velocity range is considered too small, given the continuing reduction in velocity that results from interferences in the transporters column traffic.

The growing mass of tanks, already reaching a level of 62 - 63 tons and its further expected increase up to more than 70 tons, resulted in occurrence of a wide range of articulated vehicles to transport tanks and heavy equipment with carrying capacity of 70 - 75 tons. At the same time, the maximum velocities of transporters movement increased up to about 80 - 85 km/h. The increase in carriage capacity and thus growing total weight resulted in a need for applying engines that are more powerful. While the older articulated vehicles had engines with a power of 300 - 380 kW (410 - 520 hp), the new trucks have much more powerful motors of 515 - 610 KW (700 - 830 hp). Some limitations should be expected in further growth of engine power caused by pressure to comply with standards for combustion fumes cleanliness.

The performed analysis and calculations indicated that both older and younger generation articulated vehicles have motoric properties on the roads hardly at the minimum, sufficient level. It becomes necessary to increase the maximum power of engines. The occurrence of larger slopes in real conditions will force to shift to lower gears, which leads to a reduced motional velocity, a traffic disruption, and thus having a negative impact on the safety.

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