

# Technical inspection of vehicles in order to eliminate JACKKNIFE accidents

**Danislav Drašković**

Republic Administration for Inspection Affairs of the Republic of Srpska, 051 334 607, d.draskovic@inspektorat.vladars.net

**Tomislav Vujinović**

Pan-European University APEIRON u Banja Luka, College of Traffic Engineering, the Republic of Srpska, Bosnia and Herzegovina, tomlav.d.vujinovic@apeiron-edu.eu

**Radoje Karadžić**

International University Travnik, Bosnia and Herzegovina, karadzic.radoje@yahoo.com

**Jovo Davidović**

Institute for Occupational Safety and Health, Banja Luka

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**Abstract:** Traffic accidents involving articulated vehicles are characterized by severe consequences and great material damage. Particularly accidents involving articulated vehicles such as tractors with semi-trailers have these aforementioned characteristics. In a large number of accidents involving these vehicles, the main cause of the accident is the human factor, while in others it may be caused by technical failure on the tractor or semi-trailer, road conditions, unfavorable road characteristics, etc., or a combination of several conditions. According to the NHTSA data, about 6 million traffic accidents occur in the United States annually. Heavy goods vehicles are involved in about 10% of all accidents, of which more than 50% of accidents involve tractors with semi-trailers. Accidents involving tractors are caused by technical failure on vehicles in more than 30% of cases, which is significantly higher than in traffic accidents involving other types of vehicles. The most common form of these traffic accidents is a semi-trailer skid, also called jackknifing.

This paper explains the most common causes of jackknife accidents, as well as the phenomenon that is closely related to this type of accident, which in theory is called trailer swing. Special emphasis is given to the methodology of technical inspection of vehicles as a factor of preventive actions in order to eliminate technical malfunction of articulated vehicles as the cause of the destabilization of tractors or semi-trailers.

**Key words:** traffic accidents, articulated vehicles, jackknifing, trailer swing..

## INTRODUCTION

Traffic accidents involving heavy goods vehicles generally end up with very severe consequences, both in terms of the victims and the pecuniary damage. In the overall structure of traffic accidents involving heavy goods vehicles, there is a significant number of those caused by external-objective factors, such as technical failure of vehicles, current malfunctions, state of the road surface, etc. According to the NHTSA data (*National Highway Traffic Safety Administration*), about 6 million traffic accidents occur in the United States annually [5]. Heavy goods vehicles are involved in about 10% of all accidents, of which more than 50% of accidents involve tractors with semi-trailers [6].

Technical defects or malfunctions cause approximately 30% of accidents involving this category of vehi-

cles. One of the most common causes of traffic accidents arising from technical defects is the failure of the braking system, which can lead to a semi-trailer and/or towing vehicle skid. If this skidding is more intense, it can lead to a gradual or sudden reduction of the angle between the longitudinal axles of the towing vehicle and the semi-trailer with respect to their joint connection. This phenomenon is called "*jackknifing*". If, for certain reasons, only semi-trailers skid, this is called "*trailer swing*".

## JACKKNIFING

*Jackknifing* is a term that refers to a random, uncontrolled folding of an articulated vehicle, i.e. a situation when the tractor with a semi-trailer skids in the way that the towing vehicle and the semi-trailer begin to move towards each other, whereas the semi-trailer slides laterally, so

that, practically, the two parts of the vehicle approach laterally to each other [3]. Each skidding of a semi-trailer greater than  $90^\circ$  is defined as a *jackknife* position, but at some point in time the vehicles can separate or fully connect, when there is a characteristic lateral contact between the towing vehicle and the semi-trailer. In the case of jackknifing at high speeds, there may be a rollover of the articulated vehicle [4].

*Jackknifing* can occur in two ways:

- **when the rear of the towing vehicle skids**, the tractor's rear wheels lock up, while the semi-trailer continues moving forward, it pushes the towing vehicle to the side and thus rotates it;
- **when the semi-trailer skids**, due to wheel lock-up or for some other reason, it slides and thus approaches the towing vehicle.

The term *jackknifing* is based on the movement of the semi-trailer and the towing vehicle to one another, which resembles the acute angle of a folding pocket knife.



Picture 1. An example of jackknifing

In most cases, when a *trailer swing* or *jackknifing* occurs, the driver is not able to control the movement of his vehicle or semi-trailer, as both of these occur suddenly. The consequences of these phenomena can be milder if only a part of the articulated vehicle slides off the road, or very serious if there is a contact with another participant in the traffic or a rollover of the articulated vehicle.



Picture 4. Jackknifing consequences

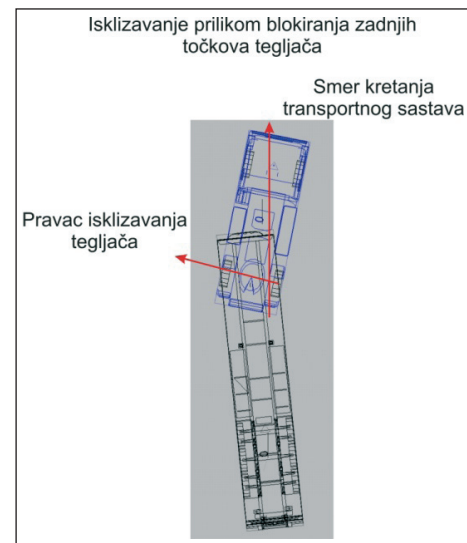
## CAUSES OF VEHICLE DESTABILIZATION THAT MAY LEAD TO JACKKNIFING AND TRAILER SWING

Due to the special connection between the towing vehicle, the semi-trailer and large mass, after initial destabi-

lization, the skidding process runs uncontrollably and most often ends with the vehicle sliding off the road. On two-lane roads, due to skidding, a part of the semi-trailer switches to the other traffic lane, which often causes collisions with vehicles moving from the opposite direction.

The most common causes of initial destabilization and *jackknifing* are [7], [8]:

- Braking on a slippery surface - leads to locking of the drive axle wheels and skidding;
- Locking the steering axle wheels of the towing vehicle - leads to the rotation of the towing vehicle around the front axle, while the semi-trailer continues moving straight forward;
- Locking the drive axle wheels of the towing vehicle - creates a difference in the braking forces between the drive axle and the axle of the semi-trailer;
- Locking the semi-trailer's axle wheels - primarily leads to *trailer swing*, which can lead to *jackknifing*;
- Sharp turning, sudden steering wheel rotation - leads to skidding of the towing vehicle;
- Rapid reduction in gear, when the towing vehicle is rapidly slowing down and skidding;
- Bad brake balance - causes uneven braking and skidding of a part of the articulated vehicle.



Picture 2. An example of *jackknifing* when the rear of the towing vehicle skids

**Isklizavanje prilikom blokiranja zadnjih točkova tegljača**- Skidding when the tractor's rear wheels lock up

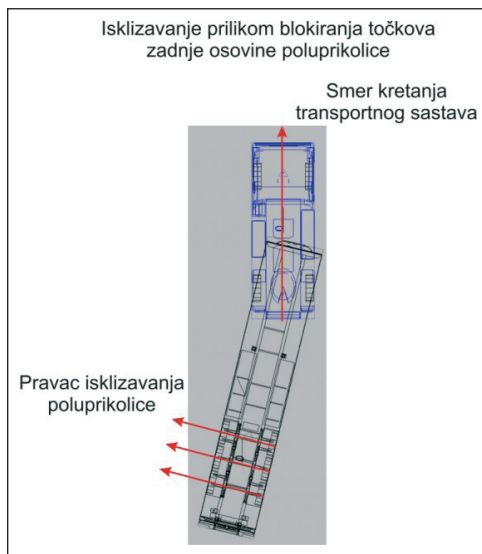
**Smjer kretanja transportnog sastava**- Line of travel of the articulated vehicle

**Pravac isklizavanja tegljača**- Direction of slide of the tractor

**Isklizavanje prilikom blokiranja točkova zadnje osovine poluprikolice** - Skidding when the semi-trailer's rear axle wheels lock up

**Smjer kretanja transportnog sastava**- Line of travel of the articulated vehicle

**Pravac isklizavanja poluprikolice**- Direction of slide of the semi-trailer



**Picture 3.** An example of *jackknifing* when the semi-trailer skids

When a semi-trailer skids or swings to one side, this is known as *trailer swing*. It occurs when the semi-trailer's rear wheels lock up or on a slippery road surface in a curve when the vehicle is moving at a high speed, which may lead to side skidding of the semi-trailer.

Under certain conditions, if it comes to skidding and to a sudden slowdown of the towing vehicle, such movement may also lead to *jackknifing*. The above phenomena may also occur due to more intensive braking when the semi-trailer is not loaded. Namely, if the semi-trailer is empty, the contact surface between the semi-trailer's wheels and the substrate is reduced in case of braking, which directly affects the difference in the braking force and the occurrence of one of the aforementioned destabilization types of the articulated vehicle.

One of the most common causes of *jackknifing* in case of articulated vehicles is the unevenness of the braking forces on the towing vehicle and the semi-trailer, which may occur due to a failure of the braking system. The initial destabilization and rotation of the semi-trailer may also occur due to a little mismatch or delay in the response of the braking system of the semi-trailer.

Statistics show that the occurrence of *jackknifing* is not very common, but it is present in even 5.5% of all traffic accidents of freight vehicles with fatal consequences [6].

## ANTI-JACKKNIFE SYSTEMS

Over the years, systems have been developed to prevent the occurrence of *jackknifing* on articulated vehicles. Attempts to find some construction solutions which could limit the angle of the longitudinal axles of semi-trailers and towing vehicles have not proved practical, given the limitations of articulated vehicles when turning in sharp curves and serpentines, at roundabouts, or when maneuvering at terminals.

Much more successful was a system that prevented the towing vehicle's wheels from locking up during braking, i.e. the ABS system (*Anti-lock Braking System*) [1], [2]. Since this system has become a part of mandatory equipment for heavy goods vehicles, this has significantly contributed to the reduction of *jackknifing* caused by locking of the towing vehicle's wheels. This system also provides more uniform braking forces on the towing vehicle and the semi-trailer, which also used to be one of the causes of their initial destabilization.

In addition to the above mentioned *jackknife* prevention systems, there is also a *load-sensing* device that regulates brake pressure. It is based on varying the pressure on the rear brakes in the case of heavy load or heavy braking, which prevents from big differences in the braking force between the towing vehicle and the semi-trailer.

Some vehicles are equipped with a lever in the cab which regulates the braking of semi-trailers. Using this lever, it is possible to slow down or brake only on the semi-trailer, without using the brakes on the towing vehicle. Theoretically, this is a safe way to prevent from *jackknifing*, but the use of this system has recently been reduced as there appeared a new problem of excessive use of semi-trailer brakes and the minimal use of towing vehicle brakes. Braking only with the help of semi-trailer brakes causes more overheating and faster wear of semi-trailer brakes, while the towing vehicle brakes remain virtually unused. This would cause uneven wear of brake lining, so that the braking system's condition of the towing vehicle and the semi-trailer were different. In the case of an unexpected danger and the need to stop the vehicle by forced braking, the driver would reflexively press the foot brake of the towing vehicle, which in some cases led to the locking of the towing vehicle brakes, while the semi-trailer brakes remained unlocked, which created the necessary conditions for the occurrence of *jackknifing*.

More recently, in order to allow more efficient braking of semi-trailers, and therefore of the whole articulated vehicle, towed vehicles are equipped with an electromagnetic brake which in practice has so far proved to be an effective way to prevent from *jackknifing*.

Certain preventive actions can prevent from *jackknifing*, even without the use of advanced systems to eliminate possible occurrence of this phenomenon. The following precautions are generally recommended:

- Whenever possible, ensure that the semi-trailer is loaded;
- Frequently checking the position of the semi-trailer in relation to the truck via side mirrors;
- Controlling the speed of the vehicle in situations that can lead to *jackknifing*;
- Avoiding sharp braking and sudden maneuvers;
- High-quality technical inspection of the articulated vehicle.

Another action that could help to avoid *jackknifing* in critical situations is increasing the speed of the towing vehicle, as this prevents from skidding of the semi-trailer and its lateral approach. However, increasing the speed of movement is not always possible, especially when forced braking is undertaken in order to avoid encountering obstacles or collisions with other vehicles.

## TECHNICAL INSPECTION IN ORDER TO MANAGE THE RISK OF JACKKNIFING AND TRAILER SWING

Previous studies have shown that the most common causes of such accidents are inadequate driving technique, i.e. sudden maneuvering with the steering wheel with or without forced braking. In addition, it is necessary to educate the drivers of articulated vehicles about the impact of the load on the semi-trailer on the stability of the whole articulated vehicle as a system in cases of sudden braking or initial skidding.

However, a very common cause is also a technical defect of the vehicle or technical failure of the braking system. For this reason, it is very important to check the condition of the braking mechanism and to adjust the condition of the braking mechanism, i.e. braking forces, on the towing vehicle and the semi-trailer.

Unfortunately, the approach to testing the technical suitability of articulated vehicles in technical inspection service stations is very often lumpy and improper. Fictitious technical inspection of articulated vehicles or tractors without semi-trailers is done. Often, technical inspection of articulated vehicles is done in an improper manner, especially in service stations that do not record the axle load of the vehicle.

The braking system test of the articulated vehicle is done according to:

- the mass of the empty vehicle and
- the maximum permissible mass.

Although it does not provide a complete picture of the system's efficiency, the procedure based on the empty vehicle mass is mainly applied.

Technical norms are prescribed by the Rules on dimensions, total mass and axle load of vehicles, on devices and equipment that vehicles must contain, and on conditions that must be met by devices and equipment.

In accordance with the above mentioned Rules:

- The brake coefficient is prescribed in the range:
  - Service brake  $K \geq 45\%$
  - Auxiliary brake  $K \geq 20\%$
- Activation force  $\leq 6.5$  bar
- Difference of braking force on wheels of the same axle
  - Service brake  $\leq 25\%$
  - Auxiliary brake  $\leq 30\%$
- Inequality of braking force on the wheel – oval-

ity indicator of the contact surface of brake drums  $\leq 20\%$

Brake coefficient  $k$

$$k = \frac{\sum_{i=1}^n F_{ki}}{G} 100 [\%] = \frac{m a}{m g} 100 [\%]$$

Where:

- $F_{ki}$  braking force at the  $i$ -th point,
- $n$  number of wheels,
- $m$  mass of the vehicle,
- $g = 9.81 \frac{m}{s^2}$
- $a$  maximum acceleration achieved.

In the case of a technical inspection of an articulated vehicle, i.e. a tractor with a semi-trailer, a problem occurs in service stations that do not record the axle load, or in the circumstances in which the system is statically indeterminate, since the rollers do not accept the whole mass because the tractor's "saddle" takes over 30% of the semi-trailer's mass, due to which the mass of an empty semi-trailer is reduced by 30% of the recorded mass of an empty semi-trailer.

In these circumstances, the following procedure shall be followed:

- The brake coefficient of the articulated vehicle (tractor and semi-trailer) shall be determined:  $k_{sv}$
- The brake coefficient of the tractor after being separated from the semi-trailer shall be determined:  $k_t$

After the above operations, the brake coefficient of the semi-trailer  $k_{pp}$  is calculated.

From the equality of measured forces of articulated vehicles and forces of the tractor  $F_{kt}$  and of the semi-trailer  $F_{kpp}$ , it follows:

$$F_{ksv} = F_{kt} + F_{kpp}$$

According to

$$k = \frac{F_k}{G} \quad i \quad F_k = k G$$

$$k_{sv} (G_t + G_{pp}) = k_t G_t + k_{pp} G_{pp}$$

So that

$$k_{pp} = k_{sv} \frac{G_t + G_{pp}}{G_{pp}} - k_t \frac{G_t}{G_{pp}}$$

In such way calculated, the brake coefficient of the semi-trailer must be higher than the one prescribed by the Rules on dimensions, total mass and axle load of vehicles, on devices and equipment that vehicles must contain, and on conditions that must be met by devices and equipment.

After the measurement, the analysis is performed, and the reasons for negative marks can be as follows:

- Large rolling resistance - system failure (brake system is not activated);
- Delay of system response on individual points (uneven time response of the system);
- Insufficient brake coefficient value;
- Excessive difference in braking force on wheels of one axle;
- Inequality of braking force on the wheel – indicator of contact surface ovality.

The pneumatic braking system in the semi-trailer is equipped with an automatic braking force control regulator that adjusts the braking force on the wheels according to the load of the vehicle. As there is a large difference in the mass of the empty vehicle and the maximum permissible mass, the brake coefficient according to the maximum permissible mass is calculated for the complete assessment of the brakes.

As technical inspection is performed on an empty vehicle, the calculation of the brake coefficient for the maximum permissible mass is required.

$$k = \frac{\sum_{m=1}^n F_{km} i_m}{G} = \frac{F_{k1} i_1 + F_{k2} i_2 + \dots + F_{kn} i_n}{G}$$

Where

$k$  - brake coefficient

$G$  - maximum permissible mass

$F_{km}$  - braking force of an empty vehicle on the  $m$ -th axle

$n$  - number of axles

$$i_m = \frac{p_{m \max} - 0,4}{p_m - 0,4}$$

Where

$p_{m \max}$  - maximum pressure in the brake cylinder for the  $m$ -th axle

$p_m$  - pressure in the brake cylinder for the  $m$ -th axle when braking an empty vehicle

$p_{m \max, m}$  - written on the plate containing data about the automatic braking force control regulator valve

The equation for  $k$  has as many members as there are axles and it is assumed that the pressure in the cylinder to overcome the rolling resistance is 0.4 bar.

## CONCLUSION

Traffic accidents involving heavy goods vehicles are inherently complex and their consequences are generally more difficult than other types of accidents.

In addition to the importance that is reflected in the behavior of the driver, i.e. their skills of driving an articulated vehicle and their knowledge about the characteristics of such vehicles, it is also very important to know how a technical inspection is properly done. Regular technical inspection should be done every six months for articulated vehicles older than five years. This period of time is sufficient to achieve the effects of prevention, only if the technical inspection is done properly. Technical inspection of articulated vehicles is often done improperly, without any analyzes or described calculations, only of tractors without a semi-trailer. There are also fictitious technical inspections which are done without testing of the articulated vehicle.

As a factor of prevention, you can have an extra technical inspection of the articulated vehicle in the presence of an authorized, official and professional person at the technical inspection service station.

A high-quality technical inspection of articulated vehicles and education of driver regarding the so-called *jackknifing* or *trailer swing* can significantly reduce the risk of traffic accidents of the described type.

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