23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

METHODOLOGY FOR DETERMINATION LOADS POSITION ON THE TRUCKS

César Alberto Chagoyén Méndez
Universidade do Estado do Amazonas, UEA. Escola Superior de Tecnologia (EST). Av. Darcy Vargas, 1200 - Parque 10. CEP 69050-020, Manaus-AM, Brazil.
(cachagoyen@uclv.edu.cu)

Yamill Santiago Campos Pérez
Universidad Central "Marta Abreu" de Las Villas. Facultad de Ingeniería Mecánica., Carretera a Camajuaní km 5.5, Santa Clara 54830, Villa Clara, Cuba.
(yamillcp@uclv.edu.cu)

Hugo Mario Tavares Junior
Universidade do Estado do Amazonas, UEA. Escola Superior de Tecnologia (EST). Av. Darcy Vargas, 1200 - Parque 10. CEP 69050-020, Manaus-AM, Brazil.
(htavares@ufam.edu.br)

Constantina Álvarez Peña
Universidad de Oviedo, Campus de Viesques. Dpto. Ing. Eléctrica, - Bloque 3.1.10 - (33204), Gijón – Asturias, Spain.
(tina@uniovi.es)

Arlen Gomes da Silva
Universidade do Estado do Amazonas, UEA. Escola Superior de Tecnologia (EST). Av. Darcy Vargas, 1200 - Parque 10. CEP 69050-020, Manaus-AM, Brazil. Research group student.
(arlen_gomes@hotmail.com)

Abstract. *In this paper the main problems that entails an inadequate distribution of loads on trucks and described in detail a methodology for determining the proper position, which concludes with the completion of the installation diagrams are presented. The methodology was obtained from the solution of the particular case of a tank of liquefied petroleum gas (LPG) of 14'000 liter on a DAF CF 75.310 truck. Another result of this work is a software which allows to determine the exact position it should be the center of gravity of the load relative to the front axle and the reactions on each axis, with the possibility of evaluating different variants.*

Keywords: *Trucks, load distribution, static analysis.*

1. INTRODUCTION

Trucks as commercial vehicles are intended to transfer loads from one place to another. The mass of the article to move, more than any other factor, determines the size of the truck to be used. A small mass requires a small truck; a large mass requires a large truck, which is a simple principle, but that is often violated.

In any case, selecting the right size truck will ensure that the work will be done with any degree of reliability and within legal weight limits.

Selecting the truck not only need to worry about the total load but also by the distribution of it between the axles. This is extremely important, both from functionally and economically.

If a truck less than capacity load, means that the owner does not completely return their investment and operating costs will be high. If the truck is loaded excessively, earnings due to increased maintenance costs and potential fines due to violations of the legal limitations are reduced.

The weight distribution should be carefully analyzed, determining how much of the total weight, including the chassis, cab, body and payload, will lead the front axle and the rear axle how to not get any of them to overload. Moving load above the chassis forward or backward a few inches, it can mean the difference between acceptable weight distribution and one that does not do the satisfactorily job (ISUSO, 2013), (Council, 2011).

Improper weight distributions cause problems in several areas:

- Excessive wear or failure of the front terminal: wear at drawbar and pin (kingpin), front axle failure, excessive overloading of the front suspension, and failure of wheel bearings.

- Rapid wear of the tires: the overloading of trucks also causes harmful effects on the tires, it results in excessive deflection, uneven and premature wear on the tread, generating high temperatures (above 100 ° C in the bearing layer) that it may result in separation of the band and of the sheets. Overloading drastically reduces the useful life of tires affects the stability and maneuverability of the vehicle itself is compromised, increasing the risk of accidents (Eagletyre, 2012).

- Erratic direction: if the center of the payload is located directly on the back or slightly behind the shaft, the lack of sufficient weight on the front axle will create an effect of shaking, the direction will be erratic. This condition is magnified when the truck goes up a hill.

- Hardened Address: when loaded beyond the capacity of the front axle, the steering mechanism also will be overloaded and as a result the direction hardens.

- Unsafe operation: the little traction in the axis of the direction gives the effect of safety of the driver and equipment, particularly on wet, icy and slippery surfaces. Experience shows that approximately 30% of the total weight must go ashore by the front axle. When a truck is loaded excessively, can be a dangerous situation because they cannot always keep the minimum speed, directional control may not be accurate and insufficient braking capacity. This may cause the braking length is greater than the normal stopping distance.

- High costs of maintenance: improper weight distribution and overload causes excessive wear and premature failure of some components. The additional stresses imposed structures can bring cracks or faults in them.

- Non-compliance with regulations and laws weight: when loads exceed the legal limits established for each type of vehicle regulations and laws violate the established weight.

- Effects on the pavement: the Federal Highway Administration in the United States (FHWA) is rated trucks based on the number of axes which owns, ranging from 2 to 7axis and more, considering the Multi-trailers. This classification allows to distinguish the effects of each truck on the pavement, which has been studied by the Highway Research Center in Alabama, through the 930-564 project. But this classification does not take into account the overloads and the effects they produce (Turochy, 2005).

To place loads in position is necessary to perform a set of calculations that not all companies involved in these tasks are performed by or if they retain some discretion. Must pay attention to the combination or reason "truck length/length of the load" (Collier, 2012). The purpose of these calculations is to get the best location of the load on the chassis to transport the maximum payload without exceeding the maximum permitted axle weights, taking into account legal and technical constraints (SCANIA, 2010; NISSAN, 2010), (García-Pozuelo, 2007) and (Toner, 2013).

There are some software which allow the load distribution (LoadXpert, 2015) (TransSolve, 2013). One of the most relevant is the software called LoadXpert that allows the distribution of weights and calculate the center of gravity for truck, trailer, etc. Also it performs load planning on trucks, trailers or containers. Has a great diversity of types of trucks and trailers, its price is $ 1,495.00 USD.

Quite often in mechanical repair shop dedicated to the implementation and/or repair of transportation fuel (liquid or gas) is necessary to form new configurations taking place on a given truck one or several tanks or cisterns. Although it seems a simple task, as described above, it is not.

Such is the case of this research initially had made calculations on three types of tanker trucks, but for various reasons the company decided to mount it on other truck whose combination with the tank had not been calculated.

In this investigation a methodology for determining the exact position that should be the center of gravity of the load over the front axle of a truck is then established. This methodology was obtained from the solution of the particular case of a tank of liquefied petroleum gas (LPG) of 14'000 liters on a truck DAF CF 75.310 under actual load conditions of the components: the cab and the chassis truck; the tank and drawer special system of loading and unloading. It would be redundant detail how dangerous it is LPG transport through road and cities.

2. METHODOLOGY

2.1 Features of the DAF CF 75.310 Truck, the Tank and the Special System Drawer

DAF CF 75.310 truck has a PACCAR PR228/310 PS 9.2-liter engine with an output of 310 hp at 2200 rpm, transmitting a pair of 1275 Nm with Euro 5 emission levels/EEV (DAF Especificaciones, 2015).

Of the more than 10 types of axis configuration having rigid DAF trucks, this is FAT 6X4 type with two rear drive axles (DAF Configuración, 2015) and (DAF Camiones, 2015).

Cab DAF truck can be of three types: Day, Space or Sleeper. This truck has Sleeper type. Figure 1 shows this cab and dimensions necessary for subsequent calculations (DAF Cabinas, 2015).

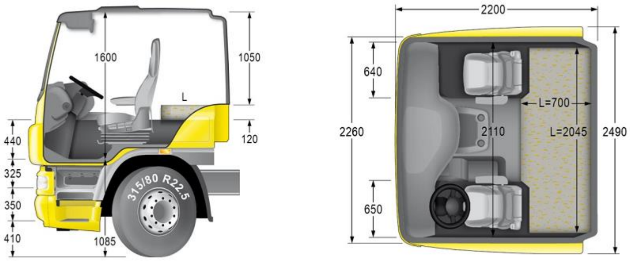

Figure 1. Cab Sleeper type of DAF CF 75.310 truck

The main features and dimensions CF 75.310 DAF truck shown in Fig. 2 and Tab. 1 and 2 (DAF Brochure, 2015).

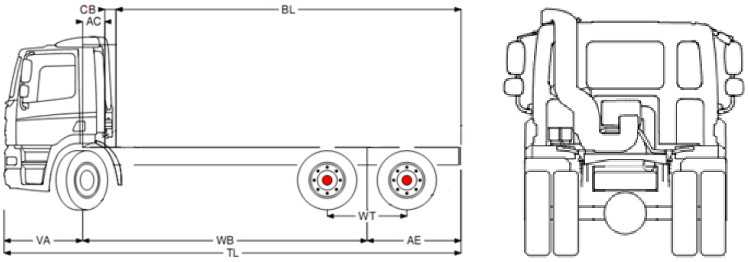

Figure 2. Main dimensions of the DAF CF 75.310 truck

Table 1. Main dimensions of the DAF CF 75.310 truck.

Dimensions (m)							
WB	AE	AC	CB	WT	BL	TL	VA
5.00	2.62	0.82	0.	1.40	6.10	8.03	1.38

Table 2. Distribution of mass, load capacity and maximum load of the DAF CF 75.310 truck.

	Chassis mass + Cab mass (kg.)	Load Capacity (kg.)	Maximum Load (kg.) (1)
Front	4435	3065	7500
Rear	4230	16770	21000
Total	8665	17335	26000

(1) These values constitute the upper limit of the load (or restriction to check) on each axle and total.

Figure 3 shown some of the necessary dimensions of the Tank to perform further calculations.

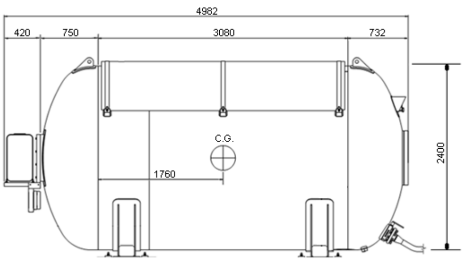

Figure 3. Main dimensions of the LPG Tank.

Documentation or passport of the Tank it was found that the mass of the same, completely empty, is 4'250 kg.

This Tank has 14'000 liters capacity. The conversion factor used in Cuba for LPG is 1'854.99 Tn/liters, which means that the mass of liquid is (14'000 liters/1'854.99 Tn/liters = 7.547210497 Tn = 7 '547.210497 kg) for a total mass of 11' 797.2105 kg.

Figure 4 shown the main dimensions of the Special System Drawer loading and unloading of the Tank.

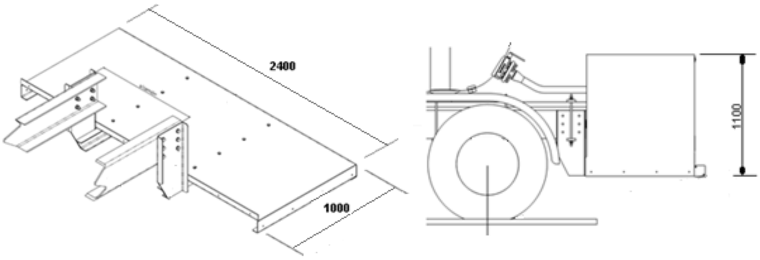

Figure 4. Main dimensions (in mm) of the Special System Drawer loading and unloading of the Tank

The mass of the Special System Drawer loading and unloading is 1'650 kg.

2.2 Load Scheme DAF CF 75.310 Truck with Tank and Special System Drawer

From the above data for each of the components (Truck, Tank and Drawer) could make a loads scheme (Fig. 5) that takes into account each of these components.

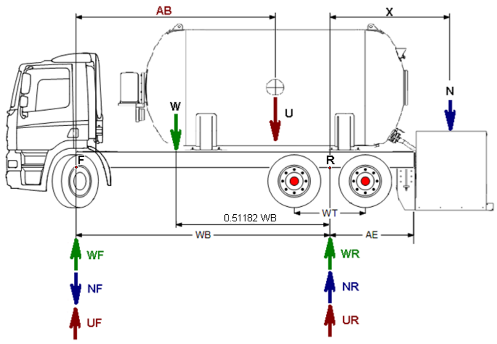

Figure 5. Load Scheme DAF CF 75.310 Truck with Tank and Special System Drawer

According catalog are knows forces the following [13]:

W – Chassis mass + Cab mass → **W**=8´665 kg., where:
WF – is the wheels reactions that support the front axle due to mass **W**:
WF=4´435 kgf.
WR – is the wheels reactions that support the rear axle due to mass **W**:
WR=4´230 kgf.
N – Special System Drawer mass → **N**= 1´650 kg.
U – LPG Tank mass → **U**=11´797.2105 kg.

The known dimensions are WB= 5.00 m, AE=2.620 m, WT= 1.40 m y X=AE+ half the width of the drawer (0.5 m)

Unknown forces are **NF**, **NR**, **UF**, **UR** but calculate them separately has no interest because only the resulting reaction is required in each axis to compare with the limit values.

The final goal is to obtain AB dimension, i.e., the distance from the front axle to Tank Gravity Center (GC).

Writing the equilibrium equations, for example to W:

$\Sigma M_F=0+ \circlearrowright$ W (0.48818WB) - WR (WB)=0 → WR=W(0.48818*WB)/(WB) = 8665(0.48818*5)/(5) = $\underline{4230\ \text{kgf.}}$

$\Sigma F_Y=0\downarrow+$ W-WF-WR = 0 → WF=W-WR = 8665-4230 = $\underline{4435\ \text{kgf.}}$

WR and **WF** values were known from catalog. Its calculation is found that the location of W is correct, that is, to 2.4409 m and 2.5591 m F R. Its calculation is verified that the W location is correct, that is, to 2.4409 m from **F** and 2.5591 m from **R**.

So could repeat this process for each independently reactions, but it is not of interest in this work.

3. RESULTS AND DISCUSSION

3.1 Methodology for determining the position should be placed Liquefied Petroleum Gas (LPG) Tank on the DAF CF 75.310 Truck.

To obtain these methodology concepts as static equilibrium, moment of a force with respect to an axis, the principle of the lever, the summations of forces and moments, were used. (Beer, 2010)

As shown in the scheme of Fig. 6 shall be determined only two resulting reactions, one in F called **RF** and another in R called **RR**.

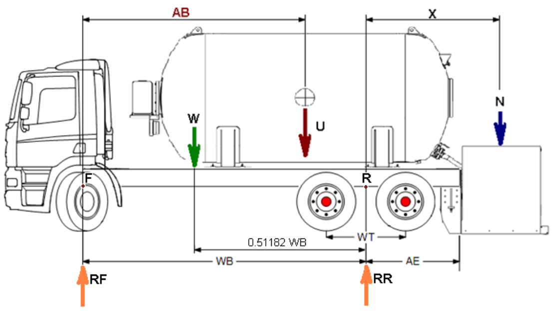

Figure 6. Loads scheme DAF CF 75.310 truck with RF and RR reactions

The methodology for determining the position of the tank on the truck will be exposed. It is based on this truck and tank type but is applicable to other transportation means and load. This methodology will be discussed in detail as if the problem manually were to be resolved or using a tab as MS-EXCEL.

1. Sum of moments about point **F** on the front axle:

$$\boldsymbol{\Sigma M_F=0} \; + \; \rightarrow \mathbf{W}\,(0.48818WB) + \mathbf{U}\,(AB) + \mathbf{N}\,(WB+X) - \mathbf{RR}\,(WB) = 0$$

2. Locate the necessary data.

Are known: **W**=8’665 kg., **U**=11’797.2105 kg., **N**=1’650 kg., WB=5m

X = AE + half the length of the drawer = 2.620+0.5=3.12m

3. Determine the possible range of installation of the tank, measured from the front axle to the gravity center of the same.

AB varies from **3930** mm (if the tank was then cab – Fig. 7) to **5568** mm in the rear of the tank coincides with the end of the chassis – Fig. 8.

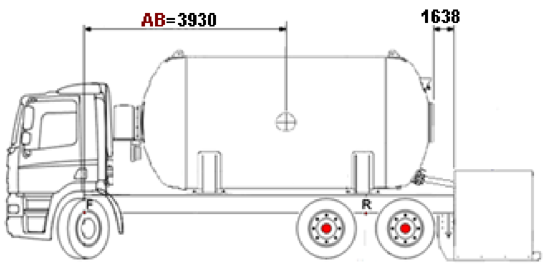

Figure 7. Distance AB=3930 mm

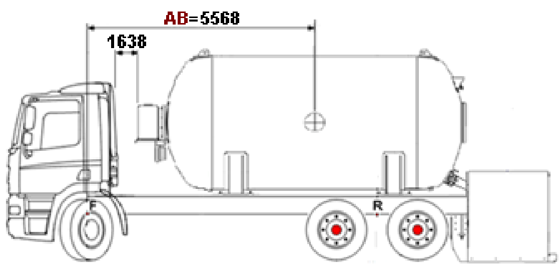

Figure 8. Distance AB=5568 mm

4. Obtaining **RR** from moment’s equation, depending on AB only:

$$\mathbf{RR}=\frac{W\,(0.48818WB)+U\,(AB)+N\,(WB+X)}{WB}=\frac{8665*(0.48818*5)+11797.2105\,(AB)+1650\,(5+3.12)}{5}=\frac{34548.3985\;+11797.2105(AB)}{5}$$

5. By varying **AB** in the range of possible placement of the tank (3.93 to 5.568 m), the regression equations curves behavior of RR and RF reactions in truck axles are obtained, which is shown in Fig. 9.

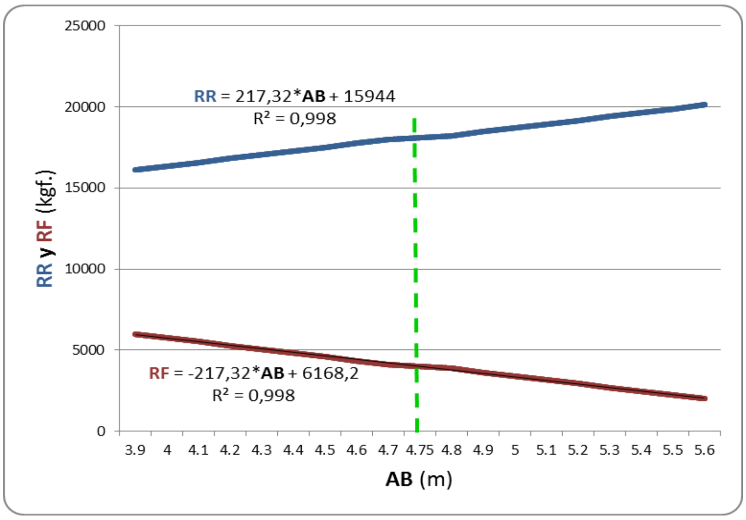

Figure 9. Behavior of RF and RR reactions and its equations

6. Check the results obtained with the limit value of RR in the rear axle:
RR varies from 16'111.5kgf. to 20'122.5kgf. changing **AB** from 3.93 to 5,568 m, which is smaller than the rear load capacity (21'000kg) so that limitation or restriction is satisfied throughout the interval **AB**.

7. Obtain **RF** value from the total mass:
By having a total mass downward of (**W**+**U**+**N**=8´665+11´797.2105+1´650=**22´112.105kg**) **RF** can be obtained as: **RF**=22112.105-**RR** for every **RR** and at the same time **AB**.

8. Check the results obtained with the limit value of **RF** in the front axle:
RF varies from 6´000.6Kgf. to 1´989.5kgf., values below the front load capacity (7´500kg) so that condition is also satisfied over the entire range.
8. Obtain the percent of the total load that constituting reactions in each axis:

% - **RR** = (**RR***100)/22112.105 % - **RF** = (**RF***100)/22112.105

9. Decide in what position of the range in which the restrictions are satisfied, place the tank:
Since both constraints are satisfied they are still various criteria to choose the exact position in which to place the tank.

A criterion may be to determine the **average** of these values, in this case, **AB**=4.75 m, **RR**=18'117 kgf. and **RF**=3'995 kgf. The front axle supports **18.1**% of the total load while the rear supports **81.9**%, somewhat distant outcomes of the recommendations of Arias-Paz (18Arias-Paz, 2008). In Appendix 2 of his book referred to the trucks that day cab trucks like this, the front axle must bear 30% and 70% rear.

Another criterion may be closer to precisely this recommendation of the author. To follow these criteria is necessary to define the distance between the tank and the cab, because insofar that these two elements are close this recommendation is best accomplished.

As a solution to the problem discussed in this research it is recommended that the tank remains located at 4.75 m of the front axle, following the first criterion described above the average of the possible values that satisfied the restrictions. Then are 820 mm between the cab and the tank that allow the manipulation by an operator of the hydraulic system located in the front of the tank.

10. Elaboration of scheme or drawing for mounting:

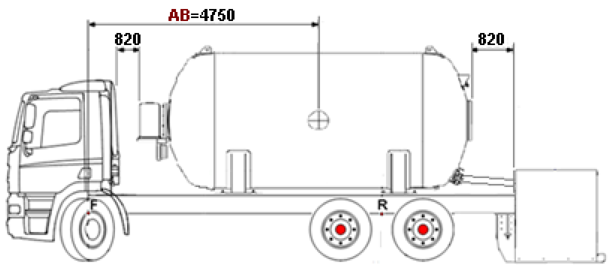

Figure 10. Scheme for the tank mounting on the truck

3.2 Implementation of the methodology in software

The methodology described above was implemented in a software program called "Load Calculation" (CalcCamion) that facilitates the work of engineers, offering the ability to assess different variants and security in the calculations are performed.

On the one hand allows determine the exact position that should be the center of gravity of the load with respect to the front axle (distance AB). Also it provides the percentage of the total load (**W**+**U** +**N**) constituting reactions in each axis. On the other, it allows an optimal distribution of the load to be transported.

The software checks the load limitations or restrictions that own each axis. When these restrictions are not complied these results are written in red. It also happens when the distance between the cab and the tank is negative, because the value that was entered AB is small.

The working procedure is as follows: after supplying the Input Data of the distances bounded in the scheme of the truck and the tank as well as the components of the masses to consider (**W**+**U**+**N**), immediately the results are obtained.

4. CONCLUSION

Determining the best location of the load on the chassis, fulfilling the axle load restrictions lets you carry the maximum payload with technical and legal security. It may also influence among others, on the duration of the mechanical transmission elements as shafts and bearings, the mechanical elements in the direction of the vehicle and durability of the rubber.

A methodology for calculating the position of the loads on the trucks elaborated. It was implemented in a software program called "CalcCamion" to analyze multiple variants safely. It was developed to calculate the truck DAF CF75.310 and LPG tanker but can be extended to other means of transport and types of loads.

In the analyzed case it is recommended that the tank stay located 4.75 m from the front axle, following the criterion of the average of the possible values that satisfying with the restrictions. Resulting RR = 18'117 kgf. and RF = 3'995 kgf. The front axle bear 18.1% of the total load while the rear bear 81.9%. Between the cab and the tank are 820 mm, which allows the manipulation by an operator of the hydraulic system located in the front of the tank.

5. ACKNOWLEDGEMENTS

Universidade do Estado do Amazonas, UEA, Manaus, Brazil; Universidad Central “Marta Abreu” de Las Villas, Santa Clara, Cuba; Fundação de Amparo à Pesquisa do Estado do Amazonas – FAPEAM.

6. REFERENCES

Arias-Paz Guitian, Manuel. *Manual de Automóviles. 2da Parte: El Chasis, Capítulo 4 Bastidor y Suspensión*. 56 ª Edición. 2008. Dossat CIE de Inversiones Editoriales S.L. Madrid, España, p.565-590. ISBN: 9788496437388.

Beer, Ferdinand P., Johnston Jr., E. Russell, Mazurek, David F., Eisenberg, Elliot R. *Vector Mechanics for Engineers: Statics (SI Units)*. McGraw Hill Higher Education; 9th Revised edition (October 2010). ISBN-10: 0071323961, ISBN-13: 978-0071323963

Collier, A. TruckView ADS. Classified Ads for 30 types of specialized Trucks. 12361 HWY 36, Bellville, Texas 77418-979-865-2992. Gordon Penny. Owner. Consulted in: November 24, 2014 and available at: <http://www.truckview.com/weight_distribution.htm>

Council of Ministers & Deputy Ministers. Heavy Truck Weight and Dimension Limits for Interprovincial Operations in Canada. MOU Summary Information. December 2011. Consulted in December 20, de 2014 and available at: <http://www.comt.ca/english/programs/trucking/MOU%202014.pdf>

DAF Brochure DAF CF). Consulted in: January 24, 2015 and available at: <http://www.daf.es/~/media/files/daf%20trucks/trucks/euro%206/cf/brochure/daf-cf-euro-6-brochure-2013-es.pdf>

DAF Cabinas CF, 2015. Consulted in: January 24, 2015 and available at: <http://www.daf.es/~/media/files/daf%20trucks/trucks/euro%206/cf/cabs/daf-cf-cab-euro-6-info-sheet-cab-64739-es.pdf>

DAF Camiones, 2015. Consulted in: January 24, 2015 and available at: <http://www.daf.es/~/media/files/daf%20trucks/trucks/euro%206/construction/daf-construction-brochure-2014-es.pdf>

DAF Configuración, 2015. Consulted in: January 24, 2015 and available at: <http://www.daf.es/~/media/files/daf%20trucks/trucks/euro%206/model%20range/axles-configurations/daf-model-overview-axle-configurations-es.pdf>

DAF Especificaciones, 2015. Consulted in: January 24, 2015 and available at: <http://www.daf.es/~/media/files/daf%20trucks/trucks/euro%206/cf/cabs/daf-cf-cab-euro-6-info-sheet-cab-64739-es.pdf>

Eagletyre Co., Información Técnica de Neumáticos - Llantas para Camiones fabricados en India, Indonesia, China. World Trade Center, piso 1- Área Comercial Calle 53 Marbella. Panamá, República de Panamá. Consulted in November 24, 2014 and available at: <http://www.eagletyre.com/informes-tecnicos-de-neumaticos-llantas-para-camiones.htm>

García-Pozuelo Ramos, Daniel. Reparto de Cargas. Laboratorio de Tecnologías IV (2007). Departamento de Ingeniería Mecánica. Universidad Carlos III Madrid. España. Consulted in: November 24, 2014 and available at: <http://ocw.uc3m.es/ingenieria-mecanica/laboratorio-de-tecnologias-iv/material-didactico/repartodecargas.pdf/at_download/file>

ISUSO Truck. Weight Distribution Concepts Section. 2013, pp 5.1-5.30. Consulted in November 24, 2014 and available at: <http://www.isuzutruckservice.com/pdf/BodyBuilder/2013/13BBG_Sec05_Weight_Distribution_Concepts%20final%20020812.pdf>

LoadXpert. CIE-TECH Inc. 5990 Auteuil. Brossard (QC), Canadá. 2015. Consulted in: January 24, 2015 and available at: <http://www.loadxpert.com/index.htm

NISSAN NP300. Normas de Carrocero para el Montaje de Carrocerías, Equipamientos y Transformaciones. Camiones. Edición: Diciembre – 2010. Consulted in: November 24, 2014 and available at: <http://www.nissan.com.mx/content/np300/manual.pdf>

SCANIA CV AB 2010, Sweden. Body Building Information. Información general sobre los cálculos de la carga sobre el eje. Consulted in: November 24, 2014 and available at: <https://pt.scribd.com/doc/149697806/Calculos-de-la-carga-sobre-el-eje>

Toner, R. Calculating Commercial Vehicle Weight Distribution & Payload Made Easy, 2013. Work Truck Magazine Online. September 2011, Work Truck – Feature. Consulted in: November 24, 2014 and available at: <http://www.worktruckonline.com/channel/safety-accident-management/article/story/2011/09/calculating-commercial-vehicle-weight-distribution-payload-made-easy/page/1.aspx>

TransSolve. TruckScience Co. Number 487420, Ireland, 2013. Consulted in: January 24, 2015 and available at: <http://www.truckscience.com/>

Turochy, Rod E., Timm, David H., Tisdale, S. Michelle. Truck equivalency factors, load spectra modeling and effects on pavement design. Final Report, Project 930-564, Auburn University, Alabama. October 2005. Available at: <http://www.eng.auburn.edu/files/centers/hrc/930-564.pdf>

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.