REALISTIC DESIGN LOADS AS A BASIS FOR SEMI-TRAILER WEIGHT REDUCTION

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One way to reduce the fuel consumption to payload ratio of heavy vehicle combinations is to reduce the empty trailer weight. This requires an understanding of the vehicle structure, assembly techniques and production process, and of special materials (e.g. high strength steel) with emphasis on strength and fatigue. But in all cases, one needs to have realistic design loads available.

This paper describes an approach to determine these loads as a first step in the process. For this purpose, tractor-semitrailer combinations have been tested under normal operational conditions, for a longer period, under monitoring of a large number of measurement data. These data have been transferred into dynamic loading data in terms of forces at each separate wheel and at the king-pin in vertical, lateral and longitudinal direction. The experience with several trailers has resulted in a cost-effective testing procedure, which also allows the assessment of representative loading cycles.

Key words: tractor-semitrailer, weight reduction, load cases

1 Introduction

The contribution of transport to CO_2 emissions has been steadily growing to 20 % in recent years. An important part of that contribution can be attributed to heavy vehicle road transport. For years, the increase of commercial vehicles has been exceeding the average growth in road vehicles, and this trend will continue. Up to 2020, road transport of goods is expected to double in size. This is due to increasing standard of living and globalisation. In addition, problems regarding accessibility, mobility and congestion, and environmental issues have increased the costs of transport (tolling, tax and other, clean environment motivated charges).

That means an increasing pressure to the transport sector to come up with innovative sustainable solutions to reduce the fuel to payload ratio, and therefore also reduce the ratio of transport cost to payload . An important factor in this discussion is the weight of the vehicle itself. Lower weight means a higher payload for the same fuel costs, which contributes to the global reduction of CO_2, and which offers

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both the transport company and the vehicle manufacturer a competitive edge. Another option is to enlarge the size of the vehicle, depending on the infrastructural limitations at hand. But also then, an optimized total weight (i.e. lower weight) is beneficial, both for the environment and for the transport industry and vehicle manufacturer.

Various projects have been carried out to reduce the trailer weight, in many cases using composite structures. An example is the ROADLITE project, see [2], claiming to have reduced the weight of a flatbed trailer by 20 %. Other examples are the ColdFeather project and its successor, the GIGA lightweight trailer [3], both aiming at the design of composite trailers for transportation of conditioned products. Other examples can be found (see for example [1]) where materials such as aluminium, sandwich material or high strength steel (HSS) is used in the chassis. With the increased yield strength, HSS offers interesting possibilities for potential weight reduction.

Reducing the semi-trailer mass requires a detailed understanding of the design and vehicle structure, of the use of (less conventional) materials such as high strength steels or composites, with special emphasis on strength and fatigue, of the production process, and of specific assembly techniques. In all cases, it is essential, as a first step, to have realistic design loads available (axles, fifth wheel) in all direction, corresponding to the circumstances actually occurring in real life for this specific vehicle combination. That means that too high safety margins have to be avoided, and a combination of so-called conservative loads at axles and fifth wheel without regarding the time history of such forces and moments should be prevented as well. It turns out that this latter approach may even underestimate the loading at critical areas, under certain conditions.

The HAN University of Applied Sciences has initiated a project FORWARD (Fuel Optimised trailer Referring to Well Assessed Realistic Design loads), aiming at the realization of tools for the vehicle manufacturer that will help him in designing semi-trailers with lower weight. This covers the following steps:

- The efficient experimental derivation of practical realistic design loads, based on a (validated) mathematical vehicle description that allows the processing of minimum sensor data to forces and moments at axles and king-pin.
- Setting up a database of such loads with reference to the varying usability conditions, to allow a more generic but still realistic approach in setting up design loads for future designs of semi-trailers
- To derive practical design criteria and principles, as a basis for further innovation and optimization of semi-trailer weight
- The verification of this approach for some practical semi-trailer designs.

Fig 1: Some examples of semi-trailers being tested

A project-team has been formed under responsibility of the HAN University, including eleven manufacturers, the Dutch Chassis and Body Work association FOCWA, the Delft University of Technology, and two companies specialized in light-weight design. First tests have been carried out for four different vehicles, and these results are exploited in the design process of one specific semi-trailer. Target of the experiments was to determine

- Forces at the king-pin in longitudinal, lateral and vertical direction,
- Forces at the axles configuration in these three directions
- Reaction forces at the various hinge points and other links in the vehicle suspension

Each vehicle has been exposed to a number of baseline load cases, covering more than 25 measurement channels (accelerations, angular speeds, displacements, pressures, strains,…). A special mathematical model has been derived and used to transfer these data to the required loading data at axles and king-pin. The final goal is to minimize the required instrumentation in a way that each manufacturer would be able to carry out such testing almost on his own without assistance, and for fair costs.

In addition to these baseline load cases, vehicle performance data have been collected under normal production conditions, with the full instrumentation on board, for at least two weeks. Load histories have been derived, giving us the understanding about the typical history being relevant for fatigue analyses.

This paper is organised as follows. In the next section, we will describe our test programme. In section 3, the transfer of the resulting test data to semitrailer loading data will be discussed. Section 4 will contain an outlook on the use of these data for the light-weight redesign of semitrailers within the context of the FORWARD project. Conclusions are listed in section 5.

2 Testing

A schematic outline of the vehicle instrumentation as originally used in the project is shown in figure 2. In advanced of the tests, wheel loads for different payloads, tractor mass, and further tractor characteristics such as position of Centre of Gravity (CoG) are determined.

During testing, we have determined brake pressures, accelerations in all directions at the trailer (chassis, wheel system, king-pin), the pressures in the air-suspension (for the front and the rearmost axles), wheel speeds, axle displacements and accelerations, body yaw rate and body lateral speed.

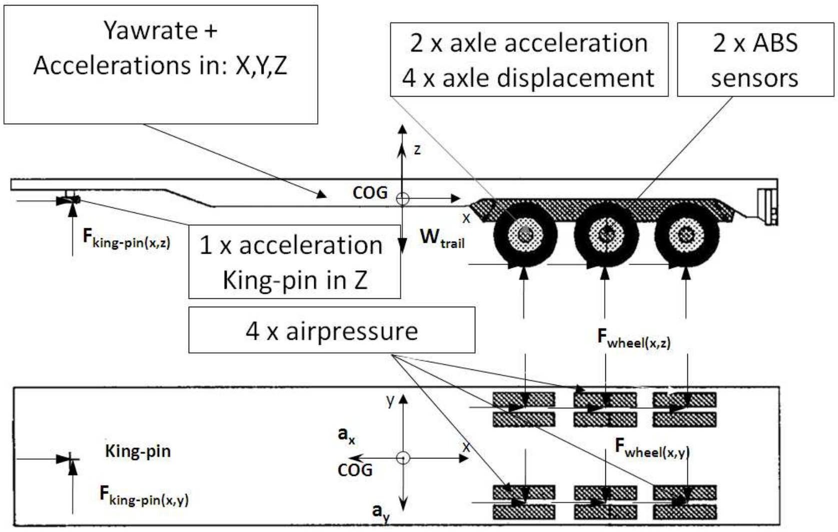

Fig. 2.: Layout of instrumentation

These data have been collected during a number of weeks, and were used to estimate trailer loads at king-pin and axles, as well as to obtain an understanding about load-history (how many thresholds, cornering, braking activities,…) as a basis for fatigue analysis. These experiments turned out to give a good understanding about the trailer loading, with some required improvements. We used straightforward mathematical relationships to derive the trailer-loading. With the final goal in mind, to redesign the trailer to reduce weight, there is a need to validate FEM model by testing, and it was decided to include strain gauges in future tests. In addition, it was decided to instrument the tractor in more detail in order to validate the dynamic tractor-semitrailer behaviour based on multi-body modeling of this vehicle combination. On the other hand, we wanted to keep the test-approach as simple as possible in order to be allow the trailer manufacturers to carry out these tests themselves for a minimum of costs. This means that we needed two approaches in our future FORWARD project:

- Validation tests (specific tests), with detailed instrumentation (40 channels) for the purpose of validation of all the (FEM, dynamic behaviour) models, and therefore also the validation of the testing-loading assessment-design approach.
- Simplified field tests (several weeks under normal operational conditions) with a minimum instrumentation, with vehicle models used to derive reliable loading histories.

3 Modelling approach and loading data

We take the x-axis along the longitudinal direction in forward direction, and the z-axis vertically upward. The first step is to derive the position of the CoG of the trailer. Trailer mass is determined from tractor mass and wheel loads, after which the longitudinal position of the trailer CoG can be determined from force equilibrium in the symmetry x-z plane. Trailer mass and wheel loads lead to the static king-pin loading. This information can be used to calibrate the air pressure data with reference to trailer axle loads.

During braking, the trailer brake torques and therefore the brake forces at the axles (neglecting wheel dynamics) are estimated from the brake pressures. Longitudinal acceleration and brake forces together give an estimate of the longitudinal reaction force at the king-pin.

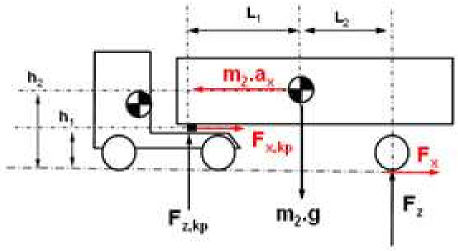

Fig. 3.: Effect of longitudinal load transfer

Pitching is accounted for by taking the equilibrium in moment around the trailer king-pin:

$$m_2.a_x.(h_2 - h_1) - L_1.m_2.g + h_1.F_x + (L_1 + L_2).F_z = 0 \qquad (1)$$

with the definitions according to figure 3. The relationship between brake force F_x and axle load F_z is known from the axle characteristics if the slip is known (which is derived from vehicle speed and wheel speeds).

The experiments were carried out for trailers with a payload between 24 and 28 ton, and with resulting trailer axle loads in the order of 6 to 8 ton per axle. Brake tests were carried out with decelerations up to 0.7 g. Typical results for these trailers are listed below:

Brake force per trailer axle	:	30 – 40 kN
Longitudinal force king-pin	:	60 – 100 kN
Vertical force king pin	:	130 – 150 kN

with a significant reduction (15 – 20%) of the vertical axle due to longitudinal load transfer during braking.

Cornering forces at king-pin and individual wheels are derived in a number of steps. Trailer mass, lateral acceleration and position of the trailer CoG are first used to determine the total cornering force over all three axles, and at the king-pin. Next the yaw rate and lateral speed at the CoG are used to estimate the slip angles at all trailer axles, and from that the individual contribution of each axle to the total cornering force. Finally the vertical position of the CoG is used to estimate the lateral load transfer and, from that, the individual sideforces per trailer wheel. The side forces are also used to determine the torque acting on the trailer (in z-direction) by the different side forces acting at the different axles. Maximum lateral accelerations of 0.3 g were obtained, Typical results for the loaded trailers are listed below:

Cornering force over all axles	: 45 – 60 kN
Cornering force king-pin	: in the order of 30 kN
Torque around trailer axle system	: 15 – 20 kNm

Typical results for braking and cornering are shown in figure 4. Observe the variation in king-pin load due to longitudinal load transfer. The separate peak values are a result of the ABS activation.

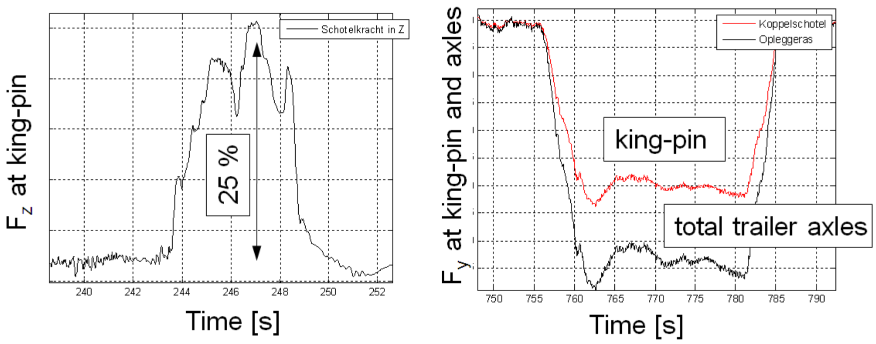

Fig. 4.: Some results for trailer loading:

- Vertical force at king-pin during braking
- Cornering forces during cornering

The vertical loading due to road undulations are derived through the vertical acceleration signals and the derived displacement signals. The latter ones serve to determine the spring forces (also derived from air pressure values). Integration of the acceleration or the differentiation of the displacements can be used to derive the damper forces. Both approaches can be used in a combined way (filtering) to improve the accuracy of the results. Air spring pressures and wheel loads can be used to derive the stationary hinge-forces in the suspension, and the spring- and damper forces plus the vertical axle and chassis accelerations are further used to derive the dynamic contributions to the suspension loads.

For different trailers, quite some different results are obtained, up to acceleration values in the order of 10 g at the axles and between 1 and 2 g at the king-pin.

The final tests carried out was low speed side loading at an angle of 90^{o} between tractor and trailer.

4 The next step, FORWARD

The results of the tests, briefly outlined in the preceding section, resulted in a number of shortcomings, that will be corrected in the next phase, denoted as FORWARD:

- Dynamic effects from the payload should be incorporated
- More experimental data about king-pin loading is required
- More variation between trailer types is required to validate design practices
- Further progress in design using FEM analysis requires more validation up to the level of stresses and strains . A first step is made in applying the available data, see fig. 5 for an outline of the present model.
- Further validation of the dynamic loading requires a tractor-semitrailer model which needs to be validated from experiments, see also fig. 6.

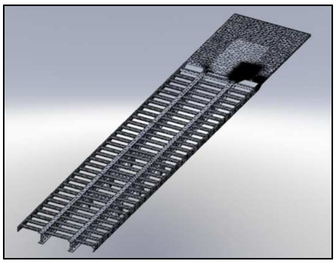

Fig. 5.: FEM model semi-trailer chassis

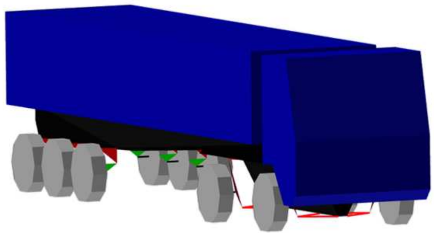

Fig. 6.: Tractor-semitrailer SIMMECHANICS model

In the next two years, about 10 different trailer will be examined experimentally. Most of these measurements will be simplified field tests as described in section 2. Based on the design and expected loading differences, at least 4 trailers will be subjected to more extensive validation tests. These results will be used as a basis for model validation and design processes to arrive at an understanding how to succeed in weight reduction for an arbitrary trailer.

The FORWARD project will also result in a fast and cost-effective test-protocol , which can be offered to trailer manufacturers or can be used by themselves.

5 Concluding remarks

We have highlighted our progress in the assessment of realistic loading as part of a programme where these loading data will result in weight reduction of trailers. But the programme is more than that. It will also lead to design practices, being feasible to a large range of trailer manufacturers, and building on a top-down process of cost-effective testing, the design of loading histories based on these test data, and the application of these design loads to lighter designs using FEM tools.

Taking the effort together with trailer manufacturers, to discuss operating conditions of their trailer, to interpret the loading as a result of these conditions and to discuss the consequences in terms of design, is a very stimulating experience, and worthwhile both for the HAN University as all the partners in the project.

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