DESIGN OF COMMERCIAL VEHICLES CHASSIS AND BODY STRUCTURE

1. Introduction

Transportation industry plays a major role in the economy of modern industrialized and developing countries. Concentrating on road transportation, the following facts are of special importance for the manufacturers of commercial vehicles:

- The total and relative volume of goods carried on trucks is high and still dramatically increasing. This results in acceptance and environmental problems.

- The transportation task itself becomes more and more specialized. Therefore, a large variety oof different vehicles is required.

- Although the share of passenger transportation in buses is relatively small compared to private cars, there is also a tendency of increasing demand in some cases like limited accessible city centers and a trend to specialization as well.

2. Design goals

2.1 Vehicle Design

The predominant goal for the design of a commercial vehicle is economy during its use from acquisition until disposal (minimal life cycle cost), and it is important to know that more than 3/4 of the cost do not include the purchase. However, requirements of safety, handling and ride comfort, legal and environmental compatibility and aesthetics are also to be satisfied.

Economy in a highly specialized industry means optimal performance, diversification of the design causing a multitude of types and as a consequence for the manufacturer to limit production cost a modular composition of the vehicles (fig. 1 and 2).

Today, design trends are
- increase in volume and weight capacity
- ease and speed up of loading and unloading - both causing a tendency to low chassis height
- increase of average speed, thus increase of engine power and breaking capacity
- decrease of maintainance effort
- improvement of the working environment of the driver
- integration of electronics for brake, transmission, power and suspension control.

2.2 Truck Chassis and Body Structure

The vehicle design starts up with conceptual studies to define size, number and location of undriven and drive axles, type of suspension, engine power, transmission, tire size and axle reduction ratio, cab size and auxiliary equipment. The selected configuration has to be suitable for the considered transportation tasks and should match the existing production line. Either a new vehicle type is generated or a certain improvement over existing types has to be achieved. Because of the fierce competition, advanced technology in engineering, manufacturing and service and strenuous work is required to be successful.
Having defined the general configuration of a vehicle, let us now concentrate on the main structural components. The most important function of the "backbone" is supporting and distributing the loads originating from

- payload including its vessels
- axles with their fixtures
- coupling device (trailer or fifth wheel coupling)
- drive train
- truck cabin including top sleeper/windshield
- inertia forces
- forced deformation
- special service functions like cab tilt mechanism, cargo handling equipment a.s.o.

In addition to the primary structural functions, the chassis has to incorporate accessories, optional and special equipment like hydraulics, and electrical wiring and piping systems.
Altogether, space is very limited and sometimes only small cross section dimensions are usable for the main structure.
The truck frame usually consists of straight or Y-shaped channel beams with varying bending stiffness and strength achieved by selection of height, flange and thickness dimensions and additional inserts. In most cases HSLA steel with yield strength above 400 MPa is used (fig. 3).
The vibration environment and the chassis deformation depends upon the service area like - paved roads, - construction sites, off-road terrain. In most cases, the truck chassis is designed to allow a limited flexibility when twisted on a wharped surface by use of open channel section beams both for longitudinal and crossmembers. This flexibility reduces the wheel load differences and therefore increases the usable in plane forces on the road surface. As a disadvantage flexibility may contribute to torsional vibration. Wharping forces being coupled at longitudinal and crossmember joints, much care has to be taken for the design of these critical fixtures. And finally, at very large street humps and potholes, the channel structure may be overloaded before a single wheel looses completely its ground contact.

Deformation of chassis must also be compatible with the superstructure, the body. Therefore either a sufficient flexibility has to be incorporated in the body itself (usually predominant in the floor design of box cargo container) or must be installed in special fixtures (e.g. three point elastic fixtures of liquid cargo tanks).

A different design philosophy may be applied for off road vehicles by using box beams with high torsional stiffness. Such a chassis must allow large suspension travel in order to keep good ground contact (see fig. 4). In this case, the total torque resulting from one wheel in the air is easily supported and there are minimal difficulties in the coupling of stiff payload containers to the frame.

In between these two general principles, a mixed chassis design makes use of longitudinal channel beams and tubular crossmembers. This design gives a reduced torsional flexibility avoiding the high cost of box beam joints (fig. 5). The torsional flexibility of this concept is shown in fig. 6 in comparison with channel crossmembers.
Joints are the most sensitive parts of the truck chassis. It is remarkable, that chassis joints of trucks are riveted or bolted, while similar joints of trailers usually are welded. The different design is due to different service conditions and structural damping is very important for the truck chassis as well as maintenance requirements.

2.3 Bus Structure

Only in the first years of bus body design, a flexible truck chassis was used together with non-structural body elements of wood and canvas resulting in the true chassis design as a contrary to the integral body design. Today, even if a channel beam chassis is used together with properly designed floor crossmembers, sidewall and roof structure, a fully integral structure is achieved (deflection behaviour see fig. 7). Advantages of a channel beam bus chassis are simplicity of design, fully equipped driveable vehicle, heavy duty suspension and sturdy load introduction members.

The bus body as a whole is a light weight, stiff structure, however significant distortion of the overall stiffness occurs at the doors and other large openings. Shear deformation at the doors is up to 10 times greater than for comparable sidewall sections. Most of the bus bodies on the European continent are fully welded tubular steel structures having similar stiffness properties. However, there are differences in the local design of welded joints with respect to dimensions, shape and application of additional stiffeners. Therefore different fatigue life performance is achieved. Fig. 8 shows a sidewall structure of a modern low floor city bus.

3. Structural Analysis

3.1 Structural Idealization and FEA

As a standard tool, the method of finite elements is used for structural analysis. The stress-strain relation of different standard elements used as beams, shells a. s.o. are reduced to forces and displacements at certain grid points. The structure is then represented by a set of these elements being connected only at the grid points where deformations and forces are related in matrix form. By the use of modern computers, even large systems can be analyzed economically, giving stresses as a result of applied forces and/or deformations of the structure (fig. 9).

The structural analysis may include linear, nonlinear and dynamic behaviour. Therefore, vibration natural frequencies, response characteristics and fatigue life of structures can be evaluated.

The design engineer is supported by the structures department already in a preliminary stage and load assumptions as well as structural idealization becomes more and more sophisticated in the later stages of product development. Loads are either computed or taken from existing similar structures until the real part exists and measurements can be made.

3.2 Multi Body System Simulation

FEA is very effective for investigation of structural problems dealing mainly with small deformations. For the major parts of the vehicle itself and their motions, i. e. the behaviour of axles, drive train, cab and body it is more convenient to use another technique, the MBSS.

Here, the complete state of motion of a specified set of rigid or elastic bodies with their inertial properties, their joints, spings, dampers a.s.o. is evaluated by integrating the equations of motion including geometric and dynamic nonlinear behaviour. The system is characterized by time functions of forces, displacements or its derivatives for any observer point to be specified. Fig. 10 shows the representation of a five cylinder engine power train with the vertical forces vs. time at the front right support bracket during engine speed-up. On fig. 11, a truck with single axle trailer is shown passing a hump while coupling forces are monitored.
MBSS is used to analyse the vibration behaviour of the whole vehicle and its major components and includes the surface contact by incorporating a tire model. Thus, safety related studies and handling characteristics can be investigated, and forces and/or displacements for FEA be obtained.

3.4 Safety

Requirements concerning safety are defined by law or professional associations. As a recent element, manufacturer liability has been extended. For a competitive producer of commercial vehicles, the judgement of the professional user is most important, thus every effort is taken to avoid deficiencies and advanced technology is applied.
Safety criterions for chassis and body structure include sufficient fatigue life of safety related parts and above this in case of overload or misuse a gradual deterioration instead of a sudden failure is required. This is achieved either by structural redundancy or by deformation and slow crack propagation rates, so defects can be detected during routine inspections.
Trucks have very stiff chassis members in longitudinal direction and the driver is reasonably well protected by his position high above the ground in case of accidents, at least in its most frequent pattern involving passenger cars. However, in order to protect those occupants, MAN has carried out investigations and tests to improve the front substructure of trucks.
In the case of bus structures, the rollover strength is of importance, as well as the resistance against side intrusion of passenger cars.
Safety related structural analysis usually includes fatigue, large deformation nonlinear FEA and the use of special crash simulation programs.

3.5 System Idealization and Verification

Both FEA and MBSS may lead to very complex and expensive problems. In order to limit effort and error risks, the most simplified model giving correct results is used in every design stage. Once the real vehicle is built, verification of measurements should be included in the testing procedure.

4. Structural Testing

Whereas theoretical investigations have the advantage to depend only upon drawings, the testing can't begin before manufacturing of the real hardware. In addition to a large number of functional, performance, corrosions and other tests, the structural tests are of special importance in order to ensure quality products. Having analized the major parts theoretically, by variation of topology, shape, dimensions and other parameters to achieve the desired product properties,only the final model has to be tested to verify the predicted behaviour. Therefore lead time and cost can be minimized in the development procedure.

4.1 Drive Tests

The complete vehicle is driven over specified test tracks under different loading conditions to reproduce the most severe service to be expected during customer use. Even cases of overload and misuse are included. In order to be approved, a certain running distance has to be completed. During test track driving, critical locations and connecting links are monitored by strain gage measurements, accelerometers and displacement or other sensors, and the signals are stored for evaluation. Then, well known severe customer service conditions are also measured to ensure the significance of the test programme.

Time functions of forces or local strain usually are reduced to histograms for better comparison with analytical or alternate results. Both fatigue life or comfort criteria can be considered.

Fig. 12 shows the force excitation of an axle control arm during test track driving, while the axle is excited at its natural frequency.

4.2 Component Tests

Critical components with safety relevant functions are usually tested on hydraulically controlled test rigs. The fixture and the loads or displacements are such that a close imitation of service conditions is achieved, to be monitored again typically by local strain measurements. Only on a test rig, the necessary statistical tests can be executed at high load frequency (sometimes exceeding $2 \cdot 10^6$ load cycles). By computer control, the load application can follow a random sequence.

Besides the geometric tolerances and the nominal material properties sometimes the production procedure even of the raw material may influence the test results. Therefore in some cases, not only the part itself is defined by the documentation, but also e.g. the manufacturer of the ingot of a forged part has to be approved by extensive tests.

5. Service Experience

After having performed theoretical evaluations and proper testing, there is much hope that a reliable, economical product with high performance is achieved. And to our knowledge, in most cases this is true. But sometimes there are surprises. Our engineers do not have enough phantasy to forsee all service conditions of our customers. Only to mention a few cases: - a truck being supported on hydraulic posts being used excessively in low gear as a drill for geological survey cracked due to vibrations of the main frame; - another truck was loaded from the back by marble blocks using a winch in such a way that first the front axle came high up in the air and later crashed down to the ground and was bent; - city buses were left running on idle the whole night causing vibration damage in the fan drive system.

Therefore in addition to all engineering skill, long time experience is necessary for the design of complicated products like commercial vehicles.

Service

cargo	street	special operations
mixed	on road long distance	quick change container
bulk	on road local distribution	crane,concrete mixer
liquid	construction site	cargo lift platform
	off road	roll off cargo system
		public services
		a.s.o.

Size

gross vehicle weight t	cab	number of axles	engine rating kW
6-10	small	2 (3)	75 - 110
12-17	long distance	2, 3	110 - 170
17-48	space	2, 3, 4	200 - 370

Body

	dropside	fifth wheel	tipper	chassis
bonneted truck		*	*	*
forward control	*	*	*	*
underfloor engined	*	*		*

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049-01

Truck Type Variation

MAN

Service

city	interurban	travel	Special Operations
			handicapped lift

Size

gross vehicle weight t	number of axles	engine rating kW
10	2	110-130
17	2	140-180-260
28	3	180

Body

	chassis	space frame
standard	*	*
low floor	(*→)	*
articulated	(*→)	*
double deck	(*→)	*

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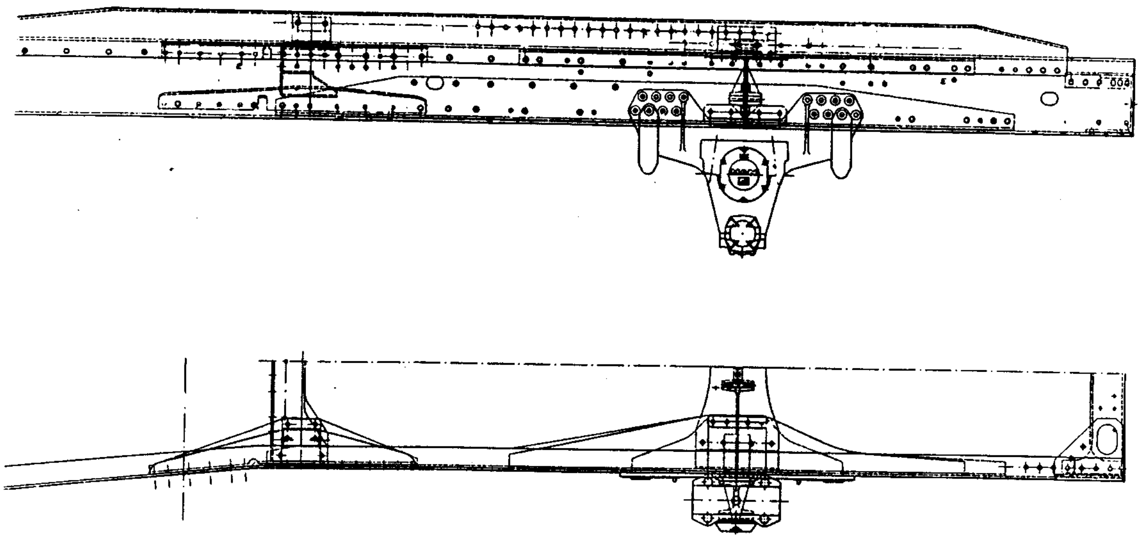
049-02

Bus Type Variation

MAN



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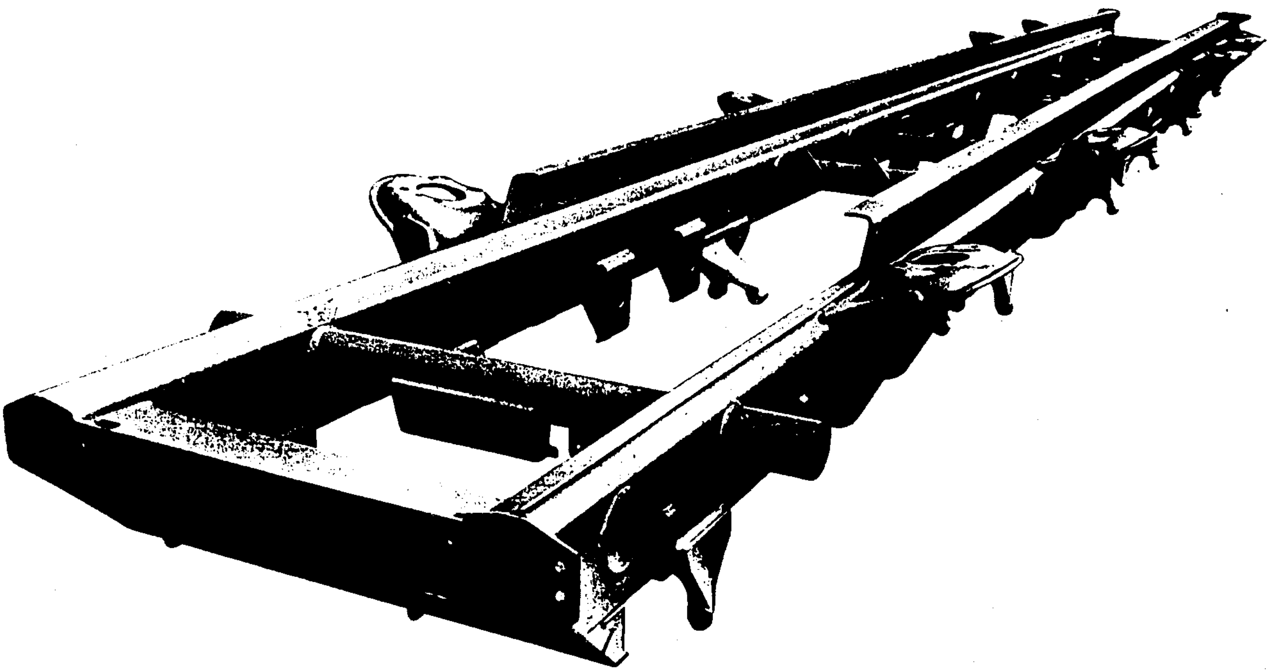
Heavy Truck, Rear Frame Assembly



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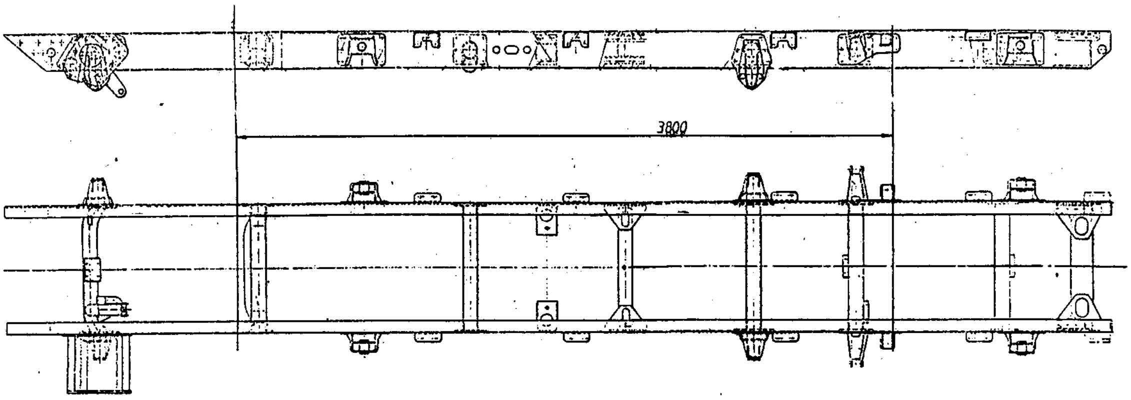
Off Road Truck, Chassis, Fully Welded Box Beams



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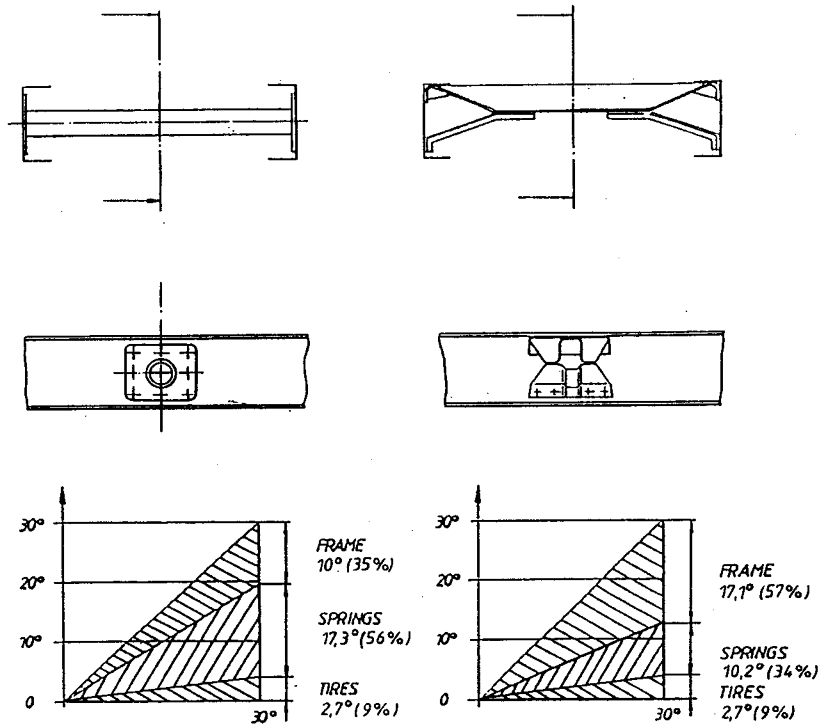
Light off Road Truck Chassis, Tubular Cross-Members



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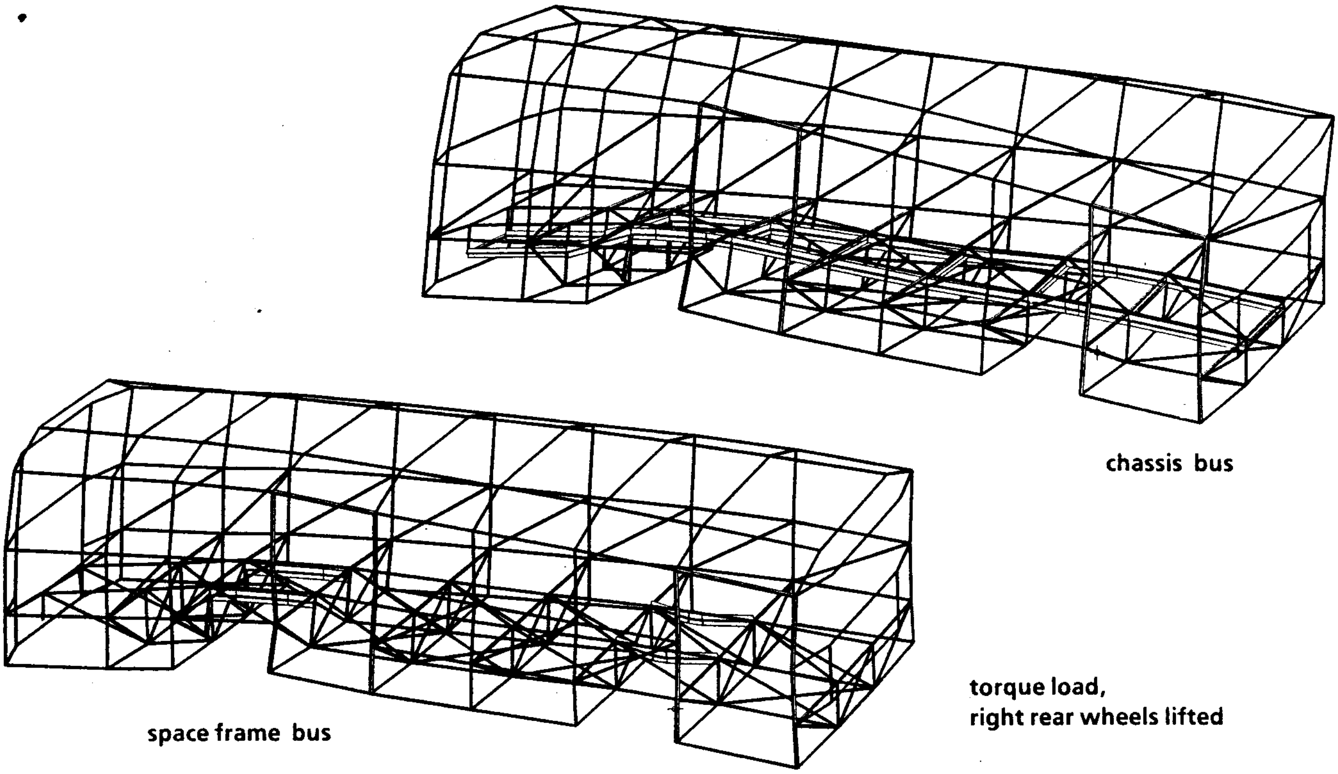
Truck Chassis Torsional Flexibility, Influence of Cross-Member Design



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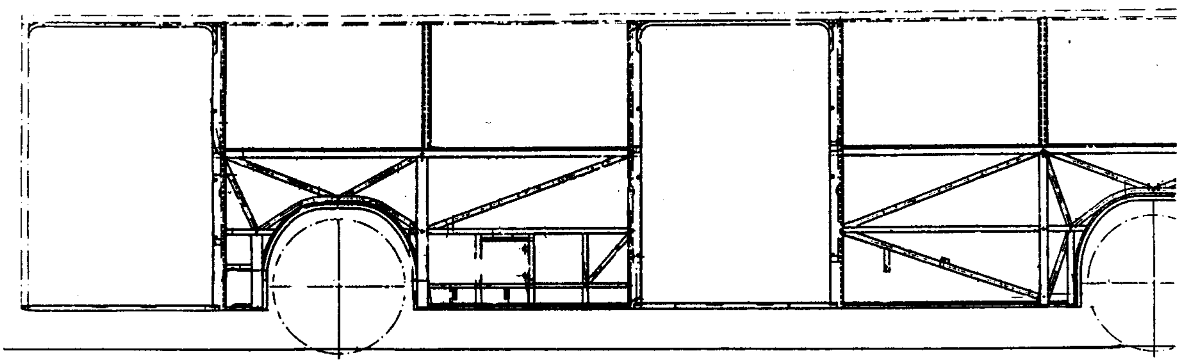
Chassis Bus and Space Frame Bus , Deformation Comparison



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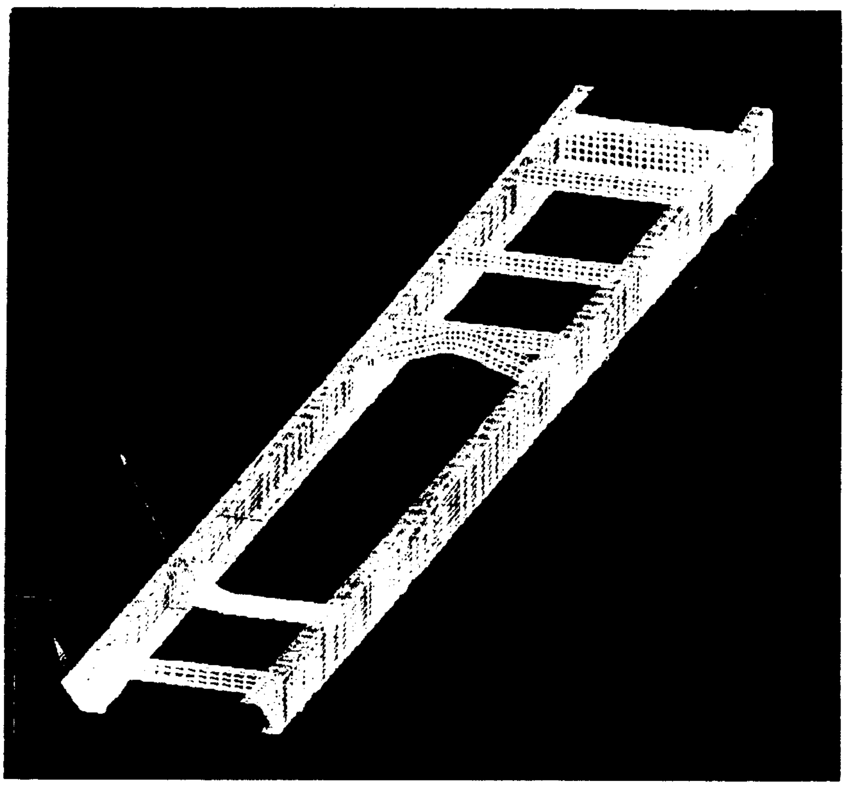
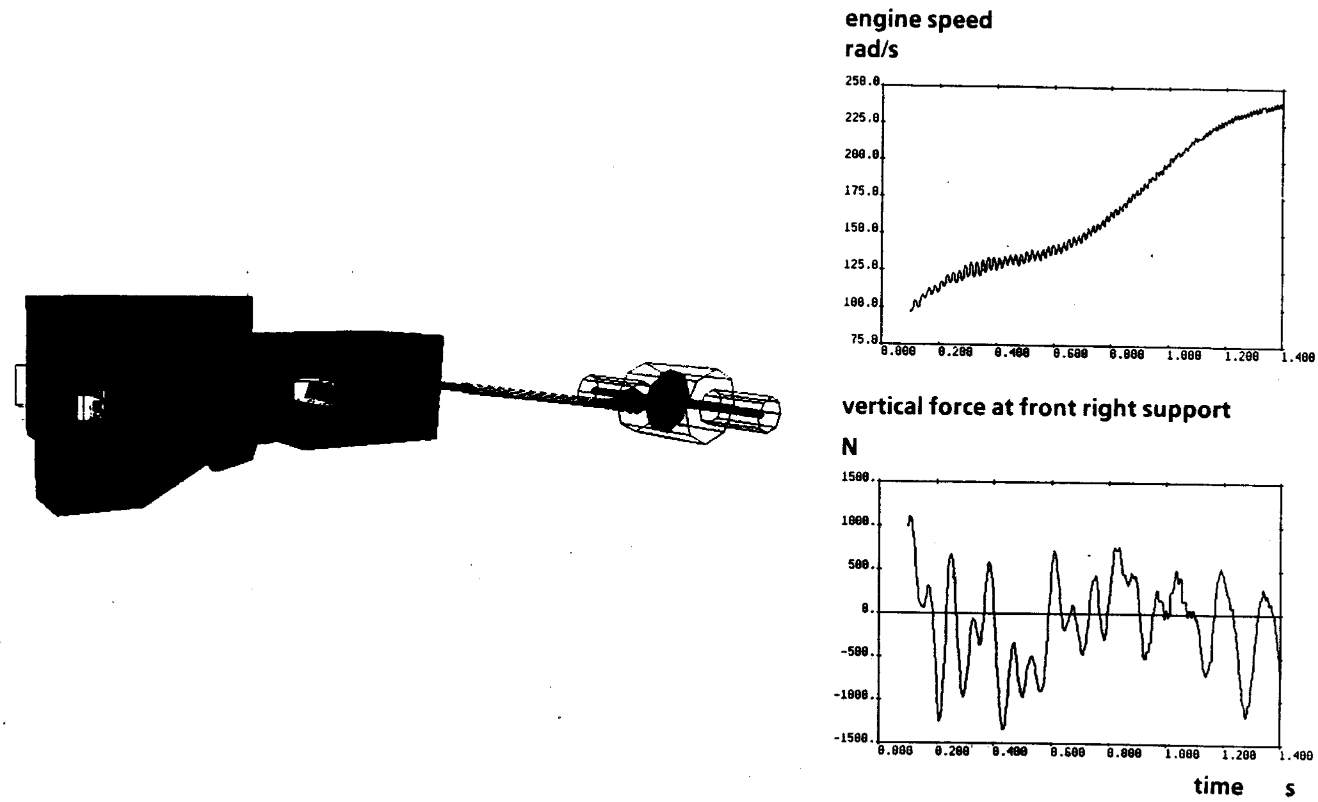
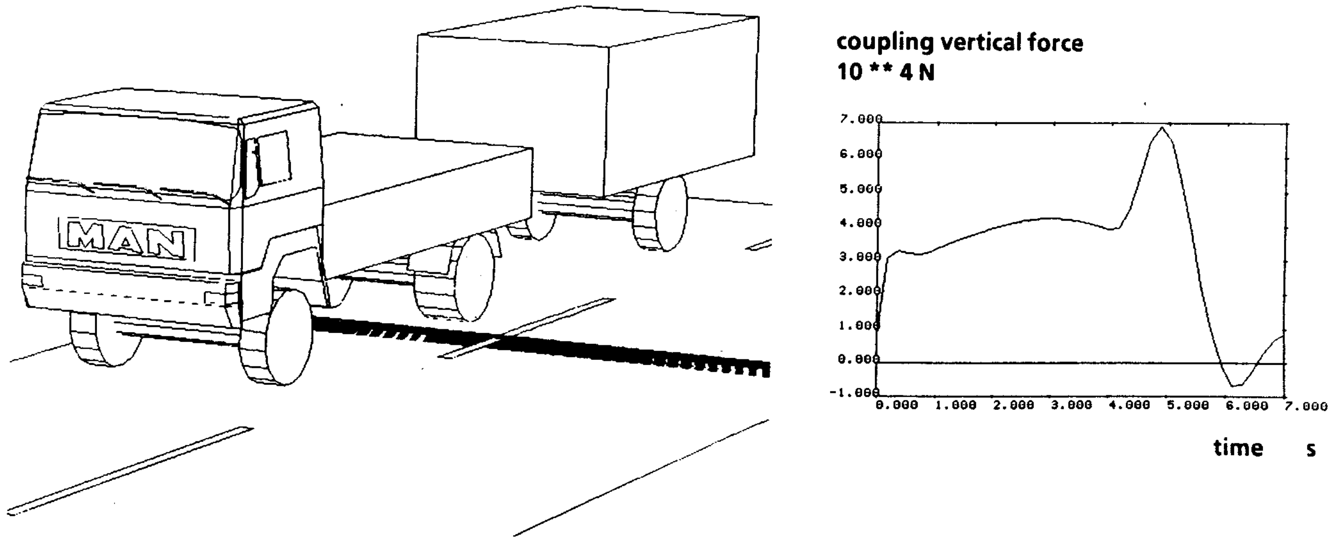
City Bus Sidewall Assembly



TKR	Finite Element Structural Analysis of Light Truck
049-09	



TKR	Multi-Body System Simulation, Five Cylinder Engine Power Train
049-010	



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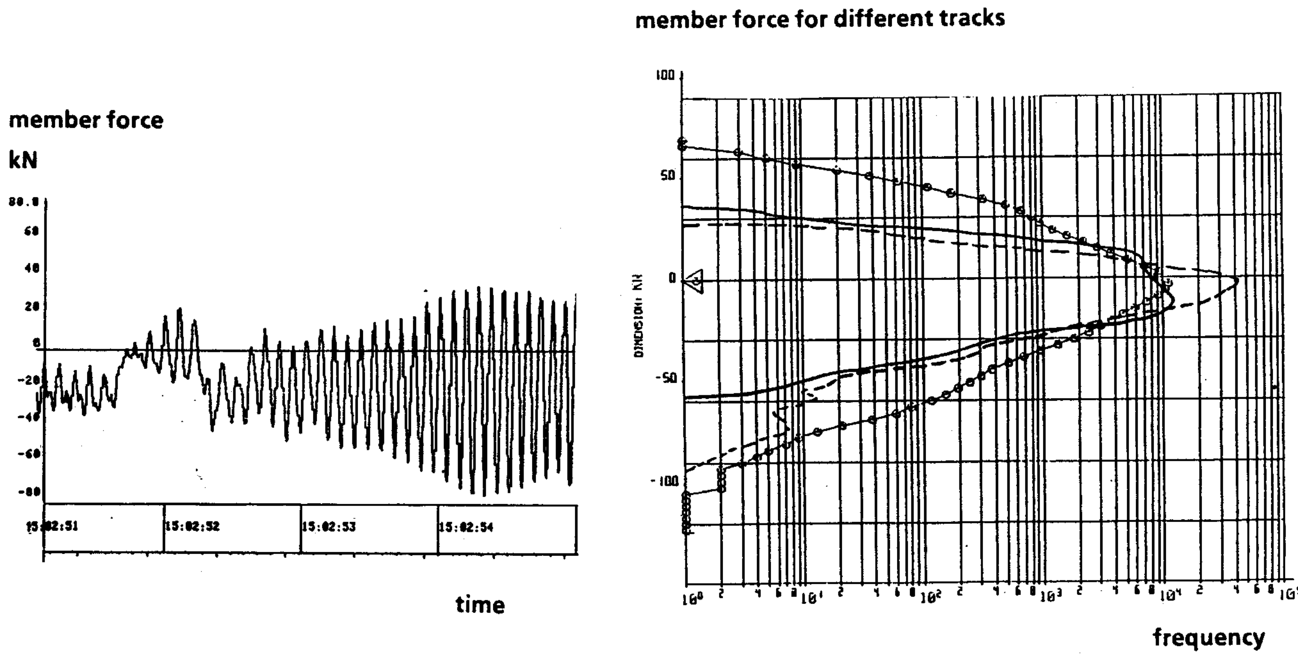
Truck with Two-Wheeled Trailer Passing a Hump, MBSS



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Suspension Excitation on Test Track