DESIGN OF VEHICLE STRUCTURES

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SYNOPSIS

Shortcomings in the design of current heavy transport vehicles are discussed and proposals made for improvements which will reduce road and payload damage, reduce maintenance costs, and improve safety, handling and efficiency.

1. INTRODUCTION

The image of the Road Transport Industry is very low in the eyes of the general public and is continuing to deteriorate further. To some extent this is a result of the irresponsible macho image projected by the media. However there are a number of technical shortcomings in the design of commercial vehicles which give legitimate cause for all sectors of the public to complain.

It is common in the Road Transport Industry to dismiss these complaints with derisive remarks about nervous little old ladies. In fact such arrogant sarcasm is far from the truth and more complaints are from travellers who drive cars and stationwagons regularly, and skillfully, as part of their profession.

Sources of legitimate irritation are:

- i) Spray
- ii) Stones and grit from ill-fitting tailgates from unsheeted loads or from excessively high loads
- iii) Trailer sway
- iv) Noise
- v) Poor HGV performance on gradients due to low power to weight ratios
- vi) Road damage
- vii) Vibration and damage to property.

Given a responsible attitude from the Industry itself and a progressive, but not unrealistic, attitude to vehicle design all of these problems can either be alleviated or eliminated.

2. CURRENT STATE OF THE ART

Contemporary truck and trailer combinations are crude and primitive. They are noisy, aerodynamically inefficient, cause substantial road and bridge damage and generally have poor stability, cornering ability and standards of road holding.

The British War Office Subsidy Truck Design of 1918 which was for a 6x4 vehicle has in it all the elements of the modern 6x4 truck. It has a pressed channel ladder frame chassis, it has the front engine, rear drive configuration which is still standard, it has a rigid tandem bogie with load sharing suspension, ackerman steering, dual tyres at the rear, drum brakes and so on.

By comparison the design of a 1985 Mercedes car is dramatically more advanced than that of the 1918 version.

3. PROPOSALS FOR IMPROVEMENTS IN SOME AREAS

Because of time limitations, this paper will ignore the improvements which could and should be made in:

- Spray suppression
- Noise (whether from tyres, transmissions, cooling systems, engines, induction or exhaust), and
- aerodynamic drag (with or without such unnecessary paraphernalia as externally mounted lights, air horns, air filters).

Instead this paper will limit itself to matters that affect the

- Roadholding
- Safety

and - Efficiency of commercial vehicles.

Above all else a commercial goods vehicle or passenger service vehicle must be efficient. It is a business tool and to survive that business must be profitable.

Efficiency however has different connotations to different people depending on their sphere of interest. To most people at this seminar it ought to mean:

- Efficient payload:tare ratios
- High cost effectiveness
- A high degree of availability.

Efficiency to the Ministry of Works will mean minimum road damage. To the ACC it will mean minimum losses due to accidents. To the clients of haulage companies it will mean shortest delivery time, minimum haulage cost and minimum payload damage.

The list can be expanded ad nauseum.

All of those factors can be improved by attention to axle layout, chassis and suspension design.

3.1 The Rigid Tandem Bogie

The rigid tandem bogie has been with us since at least, 1916. It is claimed that it is light, cheap and simple to maintain. These claims may to some extent be true where the bogie alone is considered, but, for the vehicle as a whole they do not measure up.

Firstly a rigid tandem bogie has a substantial straight line tracking tendency. To turn such a bogie it is necessary to scrub and/or to substantially distort the tyres. Both effects represent a waste of energy, and hence fuel, the energy being turned into heat. To achieve a tyre slip angle of 7° requires a 1g transverse force so that chassis frames, suspension links and wheel bearings have to be designed to safely react such forces with obvious weight penalties. Hence the INSTALLED weight of a tandem bogie is not as good as its advocates would claim.

Secondly, the tyre scrub mentioned above contributes to road damage. An exaggerated example being in-service station forecourts, whilst some roads, frequently used by trucks, show evidence of this effect in terms of the top seal being pushed into ridges. The cost to the truck operator is, of course, reduced tyre life.

Thirdly a rigid bogie forces the axles to be closely spaced rather than located in the optimum positions with respect to minimum structural weight, optimum roadholding, optimum ride and maximum payload capacity. Chassis frames become heavier again because of higher vertical bending moments as compared with spaced axles.

Finally the steering power or steering adhesion of a 6x4 tractor unit fitted with a rigid tandem bogie can be poor. Consider the case of an articulated vehicle, with a short wheelbase, conventional, 6x4 tractor unit, travelling downhill and through a right hand bend. Without braking, the tendency to travel in a straight line is a function of the kingpin thrust and the tracking characteristics of the tandem bogie. The force needed to overcome this tendency to travel in a straight line and to turn the combination through the bend is applied through only two steerable front wheels, fitted with single tyres and jointly loaded to a maximum of 5.4 tonnes. Thus steering is effected through a single axle carrying only 15% of the gross train mass and having a footprint of the two tyres involved of approximately 11% of the total road:rubber contact area for the combination. Steering power is therefore limited and, given adverse conditions of grip or road camber can easily be lost completely. Front tyre life for such combinations of less than 20,000 miles has been reported from the USA.

The first proposal therefore is:

That axles should be spaced, that in a three axle vehicle (6x0, 6x2, 6x4 or 6x6), truck, trailer or coach, two axles should be positively steered (not castoring) and that the front axle should carry a greater proportion of the load than is currently the case for truck or buses.

The benefits accruing from such a move will be:

- lighter, more reliable chassis frames, without the need for large, heavy triangular flitches and without the tendency for the chassis rails to fail at the front ends of those flitches
- lighter suspensions and longer wheel bearing life since the axial loading of the latter will be reduced
- better steering and greater steering power
- longer tyre life through less scuffing and lower running temperatures
- less road damage

and - a much safer rig.

There will be an initial capital cost penalty and it could be argued that, with additional kingpins, steering joints and, for steer/drive axles, universal joints, there will be an increase in maintenance cost. However the former should be saved by improved operating efficiency and reduced direct running costs whilst the issue of maintenance costs is less than certain because, with less stress on the chassis frame, other maintenance costs may be reduced, steer/drive axles already perform reliably under more arduous conditions on 4x4 vehicles and likewise the maintenance costs on 8x4, twin steer trucks are not prohibitive.

Technically there are no problems, the steering lock angles on a second axle are small and Hookes, Birfield or Tracta joints all provide sound reliable mechanisms. Standard inter-axle differentials can be used so that overall no new technology is needed for the power train.

3.2 Suspensions

With many current suspensions, except those fitted to most buses and coaches, a vicious circle situation exists with respect to component and sub-assembly fatigue life. So long as structures are going to be subjected to the battering caused by ineffective suspensions, they will need to be drastically overdesigned if they are to survive for even a marginally economic life. A problem is that simply making things heavier does not necessarily reduce stresses in a dynamic situation. Because of the increased inertia of the parts themselves, the heavier parts may in fact be more highly stressed and have a shorter fatigue life than the lighter equivalent.

With conventional ladder frame, leaf sprung trucks the extraordinarily ridiculous situation exists wherein the chassis frame effectively becomes part of the suspension and the springs are used to locate the axles, with all the design compromises that that involves. In Hotchkiss drive 4x4's and 4x2's the springs also react drive and braking forces. This situation was acceptable when power inputs were low, when rough, unsealed roads limited speed, rate of turn and usable brake effort and when those same roads demanded robustness as a prime requirement in suspensions and to a degree which was only practical because of the low running speeds. The system balanced for the conditons of the times. It should not be acceptable now because the technology applied lags behind the potential. Such layouts can be made to handle moderately well as can be demonstrated by many a vintage car owner. They are however a triumph of engineering over design.

The second proposal therefore is that chassis frames should be stiff in bending and in torsion.

Such chassis frames will of course rapidly suffer fatigue failures unless they are mated with long travel, low friction and preferably, progressive suspensions.

A combination of stiff chassis and soft suspension in a commercial vehicle is not without precedence and can be found in the Unimog, in Fiat's equivalent of the Unimog, in Stonefield Development's space frame trucks and in any bus or coach which has a welded steel space frame "body" structure.

There is a wide range of available springing media from steel leaf springs, through coil springs, torsion bars, air, rubber and hydro pneumatic to oleo suspensions. All have their virtues and defects. All have their place. it is a case of horses for courses.

The third proposal is that axle location is not a part of a spring's duty. Axles should be properly located by links and springs should act only as springs. Only in this way can springs be designed to give really satisfactory standards of ride.

Given this freedom, even the humble leaf spring can be made to give reasonable ride quality. Without the compromises of having to cope with axle location or torque reaction, there is more freedom of choice for spring frequency.

The suspension can be made progressive and if steps are taken to minimise interleaf friction, the leaves are made wide and flat (i.e. minimal camber) and dampers are fitted such a suspension can be relatively kind to both road and payload.

One bar to softer leaf spring suspensions at present is roll stiffness. In such suspensions roll stiffness is related to bounce stiffness whilst the spring base is limited at the front by the need to provide adequate steering lock and at the rear by the currently fashionable dual tyres. Anti-roll bars do of course improve matters.

It is possible with a number of alternative springing systems to separate out these two parameters and to arrange matters so that roll stiffness is greater than bump stiffness.

3.3 Unsprung Weight

It is worth repeating that it is not static axle load that equates to road damage but dynamic loading. Unfortunately the biggest bar to good ride standards with present systems is the very high unsprung weight and unless something can be done to substantially reduce that unsprung weight there will never be really good commercial vehicle suspensions.

The use of alloy wheels and super single tyres both help and are both excellent ideas. However with drive axles the biggest culprit is the differential and the ride of commercial vehicles would be noticeably improved if the differential were made part of the sprung rather than the unsprung weight.

The fourth, and possibly most important proposal is that:

In order to reduce both road and payload damage, and to give good ride characteristics (the driver spends up to 8 hours per day in his cab - 5 days per week), there is a need to substantially reduce unsprung weight.

One very practical way to achieve this is by way of a De Dion suspension.

Such an arrangement would give zero wheel camber change (and hence would be suitable for dual tyres), could use standard differential internals, wheel bearings etc., would be economically viable and would be strong. If preferred, inboard brakes can be incorporated, thus further reducing unsprung weight and overall this solution is eminently practical.

Preliminary design studies for such a system were carried out by the writer in 1982 and, for the coach application proposed, the conclusions were that the design was technically and commercially realistic.

3.4 Tyres

Dual tyres seem to be somewhat like Topsy - they just grew.

The suspicion is that in the dim, dark past one tyre at each end of an axle became inadequate so another was added and that is where development stopped. True there have been limitations of carcass strength and stability and of tyre running temperatures. These and, in New Zealand some myopic regulations, have delayed the adoption of super single tyres, as substitutes for duals, for almost two decades.

But how well do dual tyres load share, especially with the degree of camber to be found on New Zealand roads?

By comparison with duals, super singles are lighter, thus improving ride and reducing tare weight, they allow for wider spring bases, so improving stability, and, if used on front axles, they allow for better load sharing and steering adhesion.

The fifth proposal is therefore that super singles are preferable to dual tyres.

A further gain can be made if the tyres are low profile tyres (e.g. Dunlop's 360/50 - 22.5 tyre).

3.5 Chassis Frames

This topic has been touched upon in Section 3.2 and the second proposal was that chassis frames should be stiff.

To elaborate, chassis frames should be stiff in torsion and in bending. This is difficult to achieve with ladder frames but can readily be achieved with space frames. Good examples are the misnamed "Monocoque" bus shells, which are really space frame structures and the Stonefield Development's truck chassis, the latter having proven itself in some very arduous conditions.

The only true monocoque commercial vehicles on the roads of New Zealand today are bulk liquids or powder tankers in trailer or semi-trailer form. The higher torsional stiffness provided by these monocoque tank shells helps to improve the stability of such semi-trailers immensely, whilst the pseudo-monocoque coaches and buses can if properly designed have good reliability and excellent strength:stiffness:weight ratios.

In general monocoque and space frame structures combine light weight with high strength and stiffness and are very reliable. The initial design however needs to be very good and this implies sophisticated techniques such as finite element analysis.

The second proposal was that chassis frames should be stiff in bending and torsion. To that can now be added the fifth proposal which is:

That chassis frames should not be de facto suspensions.

A stiff chassis which is not doubling as a suspension will give the vehicle of which it is a part, better stability in turn, roll, acceleration and braking.

4. SUMMARY

The prime considerations are:

- Tare:Payload ratio
- Reliability
- Safety

Improvements in standards of ride and handling are desparately needed for both powered and towed commercial vehicles. To achieve this will require some free thinking and a break with many traditional methods. A comparison between the progress made in the design and construction of light vehicles as compared with heavy vehicles will show how poorly the latter rate as against the former.

The practicality of what has been proposed is not in doubt and most has precedence.

For example there have been and still are commercial vehicles with independent front suspension. Tatra have for some time produced a 6x6 spaced axle heavy truck with twin steer, independent suspension all round, single tyres and with differentials encased in a stiff tubular spine chassis. This is a well proven and successful vehicle. Three axle tractor units with twin steer have been produced by firms such as MAN, Maigrus Deutz, Leyland and Foden. As stated above Stonefield Developments, Fiat and Mercedes have all produced vehicles with stiff chassis and soft suspensions, whilst buses, coaches and bulk tankers have stiff space frames or monocoque structures as their bases.

Re-capping, the proposals are:

i) That axles should be spaced and that in a three axle vehicle two axles should be steering axles;

ii) Chassis frames should be stiff in bending and torsions;

iii) Axles should be properly located by links and springs should be solely springs;

iv) Unsprung weight must be minimised;

v) Super single tyres are preferable to duals; and

vi) Chassis frames should not be de facto suspensions.

It can be argued that now is the age of the proprietary truck. More than ever before truck manufacturers buy-in major components, including engines, transmissions and suspensions, rather than produce the same in-house.

It is therefore now more practical to achieve what has been advocated than ever before, especially since most of what has been advocated can be done using a good proportion of proprietary parts and since it is not necessary to incorporate all of the proposals at one time.

It is possible to progress step by step and it can be done.

SESSION F - DISCUSSION PERIOD

N. Peterken

I see him shake his head when Russell Law said we would like to do this voluntary and just with the Code of Practice and obviously David can answer that one and say why he shakes his head, won't it work David.

D. Sanford

If you try to have industry self-regulation, believe me gentlemen it doesn't work. You have got to have the design rules properly positioned, properly centred and properly done, properly laid up. It's all very well saying that industry will do this, the trailer industry, the truck industry, whatever industry you are looking at. Even doctors can't look after themselves. You have got to have a design and that is properly put, properly prepared and they work. ADR 38 has been a resounding success in Australia, it really has, the Department of Transport went out and had a look at the problems and put them altogether, it works. You could do worse than follow that. I don't say you have to follow it verbatim but it did work which is a different experience than what we had before with 35A. That's why 35A will be rewritten.

They had a Code of Practice. People said we should be looking at new systems. Nobody would do it until the law forced them to do it.

In England TRRL said for a number of years the co-efficient of the friction between a commercial road and the road is much poorer than a car in wet weather. What is the state of the art in the States at the moment with wet weather skidding of truck tyres or friction factors.

I think there is plenty of evidence that exists that confirms that is so. I can't say frankly whether it is getting much better because I don't think there has been a lot of measurements pour out of the public arena in the last few years. The last work was done late 70's early 80's, but I think measurements made by a substantial number of organisations in the world have illustrated that truck tyres have a problem in wet weather. We have made some measurements that show that they don't have any peculiar problem on dry pavement roads over tyres, in fact it is possible that they achieve a friction level of 1.0 and even a little higher at low speeds. There is a wet weather problem. There is very clear new evidence that there is a hydroplaning problem for lightly loaded tyres and in the empty condition with very little tread depth you can really have your hands full and lose traction almost completely.

This question is concerning 6 x 2. You propose that all axles should be braked. In a situation with a 6 x 2 coach which is based on an imported chassis, a 4 x 2, where you are not exceeding the manufacturers gross weight and you are adding a pusher axle so that as Jim suggested yesterday you are putting 8 tonnes on the drive axle and only 3 on the pusher, it seems to me that it would be preferable not to brake that axle because even in dry conditions that axle is only going to contribute 15%

of the braking. In wet conditions it is going to be operating much lighter than the drive axles therefore contribute less. Would you like to comment on that?

You are talking about a 6 x 2 coach. Is that right? I can't answer that one, I'm a trailer man.

P. Stone

We have a couple of people who build coaches. I think they put their axle behind the drive axle because they use rear engine. I don't recollect too many using pushers. They put the beam behind the drive axle. They put brakes on them. Sure they do. But they use load sharing suspension. There is a fairly heavy mass over the rear end because the engine is at the back. I think from memory its probably 30 size on the drive and probably 20s on the rear. They have to brake that anyway because if you take the case of 6 x 2 or 3 axle configuration with the secondary brakes requirements we have to attain there is no way in the world of stopping that front axle so we have to have your spring brakes incorporated in the partial failure mode so that if you loose your drive axle circuit, in other words you loose the rear service brakes, when you try stopping on the front brakes it won't happen, you just can't do it. So what they do is have a spring brake modulating system which picks up service response on the front axle and simultaneously exhausts the air of the spring brakes so you are still getting 3 axle braking but you have to have brakes on all axles. They are very stable because of the load sharing characteristics of the suspension.

D. Lambert

I would like to ask you a question. If we change subjects to the block truck, I believe you have been very badly informed on how they operate. While I agree with your axle movements, the majority of trailers that operate in that situation have 15" wheels or 20" wheels on 255 70 low profile tyres which considerably changes the brake charactertistics of the trailer in relation to the truck and therefore brings about a much better balance than what you suggest. So I don't think they are quite as dangerous as some people think. Would you agree?

B. Ervin

Dan who could argue with you, if you declare it is better who am I to travel all across the world to tell you it isn't.

J. Wilkinson

I think we will have to call that to a close gentlemen.