ADVANCED SUSPENSION DESIGN

TO IMPROVE STABILITY AND ROAD FRIENDLINESS OF VARIOUS TRAILER TYPES

G David Malcolm
Stability Suspensions Ltd
Auckland

PRECIS

The author became involved with light trailer instability in 1969, after a caravan (RV Trailer) he was towing took charge of his car, in spite of endeavouring to conform with all the conflicting advice that was so freely given by the supposed experts of the day.

Early research confirmed that in spite of dramatic technical developments in suspension design that had transpired for cars over the previous 70 years, none of it had found its way into trailer (caravan) suspensions.

In fact the leaf spring suspensions that are generally found under trailers worldwide in 1987 are little different from those found under horsedrawn drays of 100 years ago. A four year period of suspension development specifically for light trailers resulted in a dramatic improvement in trailer towability and stability. The system was further refined over a further 10 year period and now rates as the most advanced light trailer suspension in the world.

One of the features of this novel design has been copied by a continental suspension manufacturer, but they have not been able to incorporate all three design features, which makes STABAX the world leader in design and performance features.

The technology and experience gained is now available to the Heavy Truck Trailer Industry to use as follows:

a) To achieve inherent stability of A-Train Combinations, and other Trailer Configurations.

b) To prevent out tracking of trailers of various types in high speed curves.

c) To reduce suspension induced stress into the trailer components and king pin, through to the tractor unit.

d) To reduce suspension induced stress into the road foundation, i.e. a road friendly suspension.

e) The steer options can be from simple interconnected caster steer of the first and last axle, to power steer of the three axles to improve manoeuvreability.

The author considers that the onset of unstable towing behaviour on less than smooth road surfaces can be caused by high spring rates, which feed the vertical acceleration of the wheels and tyres into the vehicle. The demand for extremely high resistance to roll dictates that spring stiffness be several times stiffer than that required for good ride quality. In fact, what ride quality is present is due to the tyres, more than the springs themselves.

Due to high spring rates, the relative motion between axle and vehicle has been small, therefore overlooked in terms of axle steer, most of the design thought has been directed at absorbing brake torque when considering radius rod attachment. The concept of converting controlled amounts of roll into positive steer angles seems to have eluded the traditional suspension engineer.

Another feature which has been built into car suspensions since the mid 1960's, is that of suspension compliance, but once again the spin off from this design feature has been lost on both heavy suspension and roading engineers. It is my believe that a suspension must be soft riding and provide compliance before it can be considered Road Friendly.

These and other design changes will be discussed, for incorporation into new generation suspensions.

OBJECTIVE

Research has been conducted in Australia over the last 10 years, to determine the relationship between Suspension Types and Road Life.

Research has been conducted in Canada and USA on the towing behaviour of various vehicle combinations, the results of which have been able to classify and confirm the belief that combinations could be ranked into categories of stability under various manoeuvres or swerve conditions.

To the writers knowledge, very little research has been completed to find suspension designs which would contribute to improving the inherent stability of a combination while also contributing to improved stress reduction of the roading system. The cost of road building has reached the point that few, if any, country in the world can afford the expense of providing road systems that would satisfy their transportation demands.

It took a world oil crisis in 1973 to make administrators realise how wasteful of non-renewable natural resource that man can be, and experience since that time has shown that with proper management of energy, many countries today are producing more goods and services with lower fuel consumption than 14 years previous.

The objective of this paper is to discuss suspension design criteria that will improve both vehicle stability and road friendliness, which would translate into billion dollar savings worldwide, by increasing pavement life.

Component Cost

By far, more research dollars have been spent by suspension manufacturers over the years on finding lighter and less expensive components or systems, than has been spent on improving the product's ride or handling performance. The customer has also suffered from tunnel vision by demanding the least expensive suspension systems, without regard to his overall operating expenses. The dollars saved on a suspension were probably spent on chrome and paint.

Transport operators in New Zealand pay a Road User Charge, based on maximum axle load per kilometer travelled. Some operators must obviously consider the burden of R.U.C. because they opt for more axles which lowers the maximum axle load, but have they considered the loss of pay load revenue due to increased tare weight?

The effect of suspension weight reduction has resulted in short length spring designs, which have very limited vertical wheel travel, or high spring rate. The change to mono leaf or taper leaf springs has further improved weight efficiency, at the cost of higher than ever spring rate.

Suspension suppliers have endeavoured to cover a broad spectrum user base, (this process is also known as rationalisation) thus the worst case criteria has to be satisfied. Roll stiffness appears on the top of many researchers list as being the most important factor in resistance to roll over.

Spring stiffness has been designed to achieve primary roll stiffness with no regard for vehicle ride quality. Air suspension manufacturers on the other hand have had to provide auxillary roll stiffness, they often do in massive doses, negating some of the soft ride advantage when operating on rough surfaces.

We in New Zealand seem obsessed with the idea that our conditions are the worst in the world and that we require 10 tonne capacity axles to carry 8 tonne axle loads. Some operators place one further axle under the rig and run at 6 tonne axle loads, to save on R.U.C., but lose 1 tonne of payload in the process. Research of the R.U.C. axle combinations and loads reveal that 6 tonne axle loads can be very cost effective, especially so when carried on light weight 6.5 tonne suspension, fitted with single wheels and tyres.

The smart operator will see the benefits from taking a clean sheet of paper and redefining the objectives for suspension requirements.

(a) Improve ride quality without serious secondary effects such as loss of roll stiffness.

(b) Opt for wide track single wheels to reduce tare weight and allow wider spring base to help recover lost roll stiffness.

(c) Use a suspension design with high roll centre axis, thus improving roll stiffness.

(d) The combining of (b) and (c) allows tanker installation height to be lowered, thus reducing the requirement for excessive roll stiffness.

(e) Provide controlled POSITIVE roll steer as opposed to the negative roll steer inherent with traditional suspensions. High speed outracking is eliminated resulting in a safer vehicle on the road.

(f) Provide axle compliance.

Axle compliance is the designed fore and aft freedom given to an axle, as opposed to the rigid location that has prevailed to date. Axle compliance dramatically reduces shunting along the rig, thus the fatigue induced failure of king pins and draw beams, also cracking of tanker frames and shells.

(g) The combination of low spring rates plus axle compliance, along with mean axle loads of 6 tonnes compared with 8 tonnes, must contribute to a significant reduction of stress on pavement surface and road foundation.

Ride Quality/Road Stress

I once heard a road engineer quote that up to 40 km/hr, suspension stiffness had little to no effect on pavement life when the test was conducted on new, smooth, pavement, compared to the effect of increasing axle loads. The speaker left his audience with the impression that suspension stiffness did not matter, but load sharing was of uppermost importance.

I find two reasons to quarrel with that assumption, firstly, trucks don't travel at 40 km/hr anymore, and secondly, roads don't stay smooth for ever.

Taking tyres in the 900R20 to 1100R20 range, they have a natural bounce frequency of around 2.5 Hz fully loaded as a single and around 2.6 Hz fully loaded as a dual fitment. Trailer suspension at gross load of 8 tonnes have a natural bounce frequency of approximately 3.0 Hz to 3.5 Hz. Therefore the tyres are providing the primary suspension medium. As axle loads decrease, bounce frequency increases.

Until such times as low bounce frequence suspensions (1.5 to 1.75 Hz) with load sharing are tested at 100km/hr on rough road surfaces, we do not have documented evidence to support our claim that these suspensions are road friendly. These low frequency suspensions require adequate damping to prevent secondary bounce occurring. The benefits of suspension compliance would not be apparent on smooth road surfaces up to 40 km/hr either, but if the difference in towability of trailers with 3000kg axle loads are able to be directly extrapolated into heavy rigs, then considerable saving are potentially available. The rougher the surface and faster the speed the more impressive these features become. Experience in Canada with STABAX suspensions proved that the tow vehicle was the limiting factor, not the trailer, when negotiating rough surface conditions.

Generally coil springs seem to have eluded heavy trucks and trailers, the Army Unimog being an exception. KW have a torsion bar rear suspension. One concept of the STABAX Super Six Triaxle suspension uses variable rate coil springs. Hydraulic or air inter-connection for load sharing and constant height are options for the mechanical linkage. The choice of coil springs allows axle compliance without friction and wear. The suspension could also be offered as a hybrid, coil/air or coil/hydraulic. Anti roll bars can be fitted to increase roll stiffness if required.

The decision to use single wheels allows king pin steering axles to be used. Hydraulic or mechanical linkages between the first and last axle allow the wheels to steer opposite locks in corners, thus reducing tyre scuff and surface stress to the road. The interconnection between the first and last axle does not permit both axles to thrust steer off in the same direction in a high speed curve.

Yet another possibility is to employ three steered axles and power steer them in the same direction from the turntable or from the truck steering system.

A-TRAIN INSTABILITY

The quick fix for this problem as suggested by our Ministry of Transport was, Ban Them. It seems inconceivable to the writer that the established suspension industry has not taken steps to give these combinations some semblence of inherent stability to each unit of the combination.

In this day and age of Mazda RX7's active steering, and Mercedes Benz dynamic steering whereby the process of the vehicle suspension loads and cornering forces are converted into appropriate steering angles, we continue to allow dynamic suspension forces to throw truck trailers off course.

Some suggestion for achieving inherent stability of these rigs are:

(1) Suspension spring rate requires lowering overall, particularly those under the front dolly.

(2) The rear suspension of each rig requires positive roll steer, the front netural steer.

(3) Deflection steer must be eliminated.

(4) Turntables should be mounted with a three to five degree caster angle, or alternately the axle centre line should be behind the turning axis of the turntable. Perhaps combinations of the above would prove desirable.

(5) (a) Opting for a nominal axle capacity of 6.00 to 6.5 tonnes would give a 7 axle rig a GCM of 44000kg, i.e. (5x6)+(2x7 drivers), RUC, $9.6375/Tonne/1000km.

(b) An 8 axle rig running at a GCM of 44000kg has the advantage of lower RUC and very favourable tare weight, compared with the present B Train. RUC $8.685/Tonne/1000km.

(c) Furthermore a 9 axle rig running at a GCM of 44000kg has an even lower RUC, but some payload loss compared to (b) above. RUC $6.5025/tonne/1000km.

CONCLUSIONS

(a) Trailer suspensions which are inherently road friendly can be designed. Features would include, soft ride properties, hydraulic dampers and axle compliance.

(b) Trailer suspensions which are inherently stable can be designed. Features would include positive roll steer at rear. Zero roll steer at front.

Turntables should be mounted with positive caster angle and or axle setback.

(c) Nominal axle suspension and brake capacities of 6.00 to 6.50 tonnes are all that are required on New Zealand roads. These axles improve tare weight and offer lower Road User Charges.

Appendix	A	RUC 3 axle truck and 3 axle trailer
	B	RUC 4 axle truck and 4 axle trailer
	C	RUC B train
	D	Fig 1 suspension
	E	Fig 2 suspension

APPENDIX A

RUC EXAMPLE

Typical 3 axle truck and 3 axle trailer

Gross	19000	+	20000kg	39.00 tonnes
Tare	8500kg	+	5000kg	13.5
Nett	10500	+	15000kg	25.5

Type 6 / Type 37 / Cost/tonne/1000km

19 tonnes = \$216.92 20 tonnes = \$212.96 = $\frac{\$429.88}{39}$ = \$11.0223

Nett load 25.5 tonnes $\frac{429.88}{25.5}$ = \$16.858

@ 48.5% load factor = 12.3675 tonnes $\frac{429.88}{12.3675}$ = \$34.7588

Alternative:

Typical 3 axle truck and 4 axle (lightweight) trailer

Leave masses as above.

Type 6 / Type 43 / Cost/tonne/1000km

19 tonnes = \$216.92 20 tonnes = \$118.25 = $\frac{\$335.17}{39}$ = \$8.594

Nett load 25.5 tonnes = $\frac{\$335.17}{25.5}$ = \$13.1439

@ 48.5% load factor, 12.3675 tonnes = $\frac{\$335.17}{25.5}$ = \$27.100

Potential savings of 7.659 cents/km or 22%

APPENDIX B

RUC EXAMPLE

Typical 4 axle truck + 3 axle trailer

Gross	24000kg	+	20000kg	=	44000kg
Tare	9500kg	+	5000kg	=	14500kg
Nett	14500kg	+	15000kg	=	29500kg

Type 14   Type 37   Cost/tonne/1000km

24 tonnes = \$251.46   20 tonnes = \$212.96 = $\frac{\$464.42}{44}$ = \$10.555

Nett load 29.5 tonnes = $\frac{\$464.42}{29.5}$ = \$15.743

@ 48.5% load factor, 14.3075 tonnes = $\frac{\$464.42}{14.3075}$ = \$32.46

Alternate:

4 axle truck + 4 axle, (lightweight) trailer

Leave masses as above.

Type 14   Type 43

24 tonnes = \$251.46 + 20 tonnes = \$118.25 = $\frac{\$369.71}{44}$ = \$8.4025

Nett load 29.5 tonnes = $\frac{\$369.71}{29.5}$ = \$12.533

@ 48.5% load factor, 14.3075 tonnes = $\frac{\$369.71}{14.3075}$ = \$25.84

Potential savings = 6.62c/km = 20.394%

APPENDIX C

RUC EXAMPLE

B Train twin tyred tandem axles

Gross 18000kg + 13000kg + 13000kg = 44000kg
Tare 8000kg + 4500kg + 4000kg = 16500kg
Nett 10000kg + 8500kg + 9000kg = 27500kg

Type 6 Type 29 + Type 29 Cost/tonne/1000km
8 tonnes = \$184.91 + 13 tonnes = \$119.57 + 13 tonnes = \$119.57

$= \frac{424.05}{44} = \$9.6375$

Nett load 27.5 tonnes $\frac{424.05}{27.5} = \$15.42$

@ 48.5% load factor, 13.338 tonnes $\frac{424.05}{13.338} = \$31.793$

First alternate:

Single tyred triaxle + single tyred tandem

Gross 16000kg + 18000kg + 10000kg = 44000kg

Type 6 + Type 37 + Type 28
16 tonnes = \$133.65 + 18 tonnes = \$155.21 + 10 tonnes = \$93.28

$\frac{382.14}{14} = \$8.685$

Nett load 27.5 tonnes $\frac{382.14}{27.5} = \$13.896$

@ 48.5% load factor, 13.338 tonnes $\frac{382.14}{13.338} = \$28.65$

Potential savings 3.1425c/km = 9.88%

Second alternate, two single tyred, triaxle trailers

Gross 14000kg + 15000kg + 15000kg = 44000kg

Type 6 + Type 37 + Type 37
14 tonnes = \$96.47 + 15 tonnes = \$94.82 + 15 tonnes = \$94.82

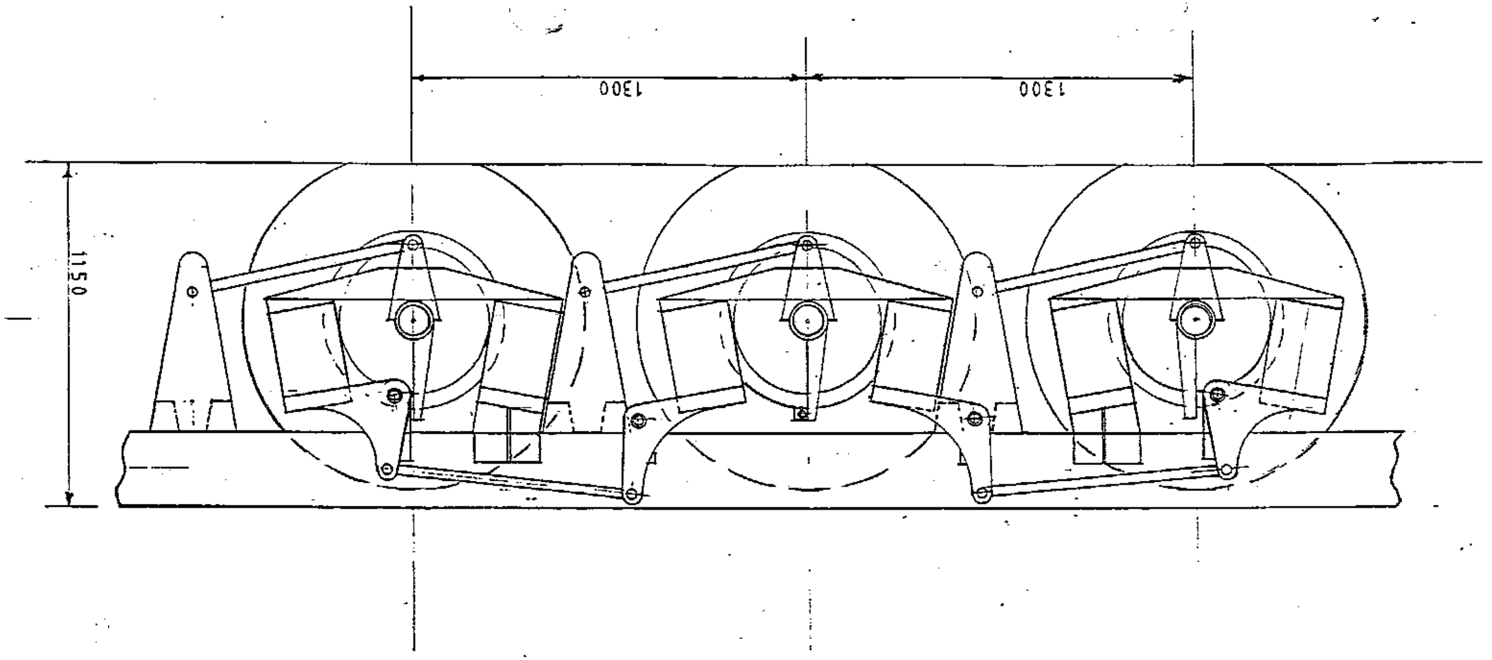
$\frac{\$286.11}{44} = \$6.5025$

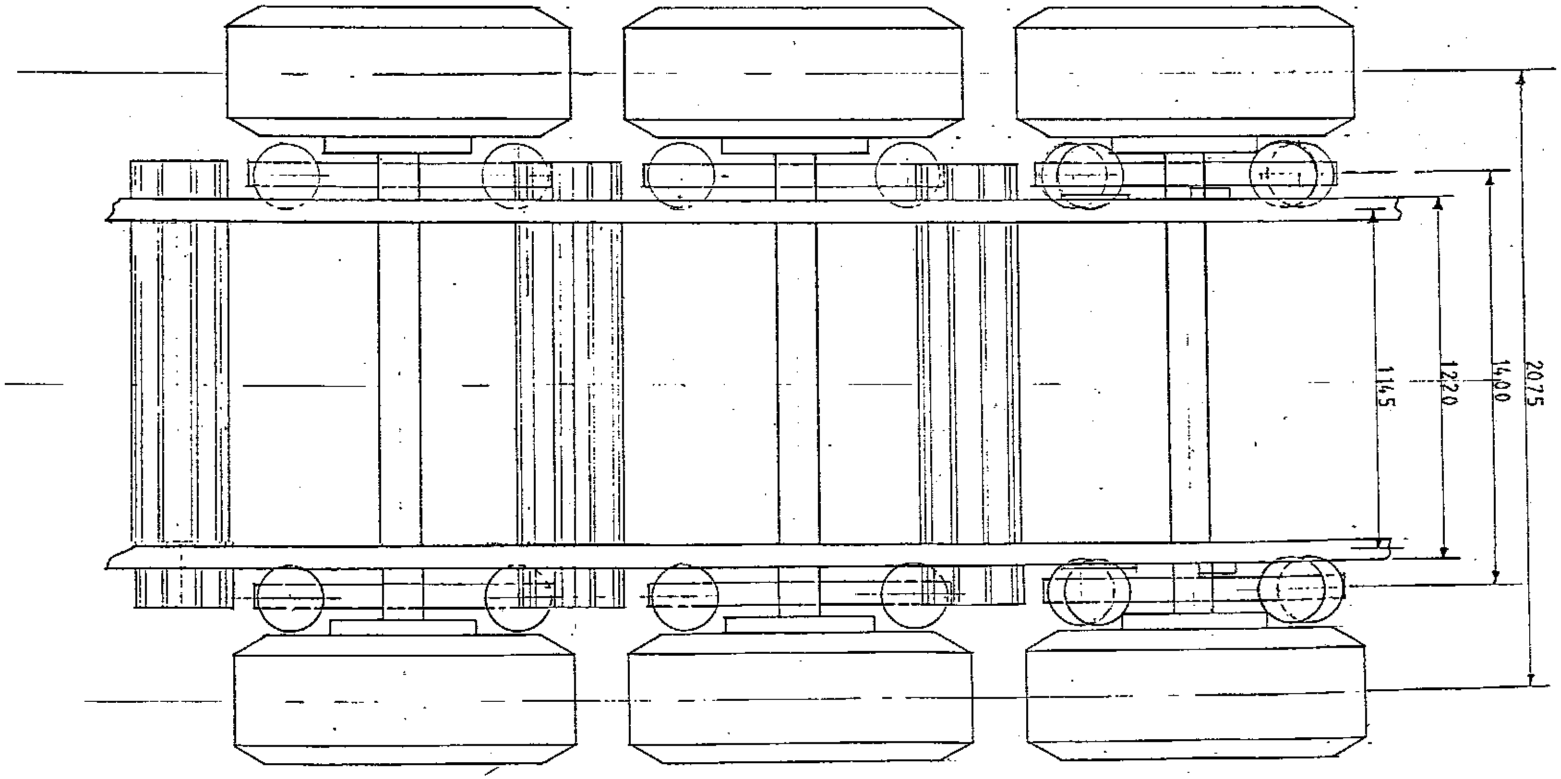
Nett load 27.5 tonnes $\frac{286.11}{27.5} = \$10.404$

@ 48.5% load factor 13.1425 tonnes $\frac{286.11}{13.1425} = \$21.7698$

Potential savings \$10.023/tonne/1000km = 31% saving

APPENDIX D

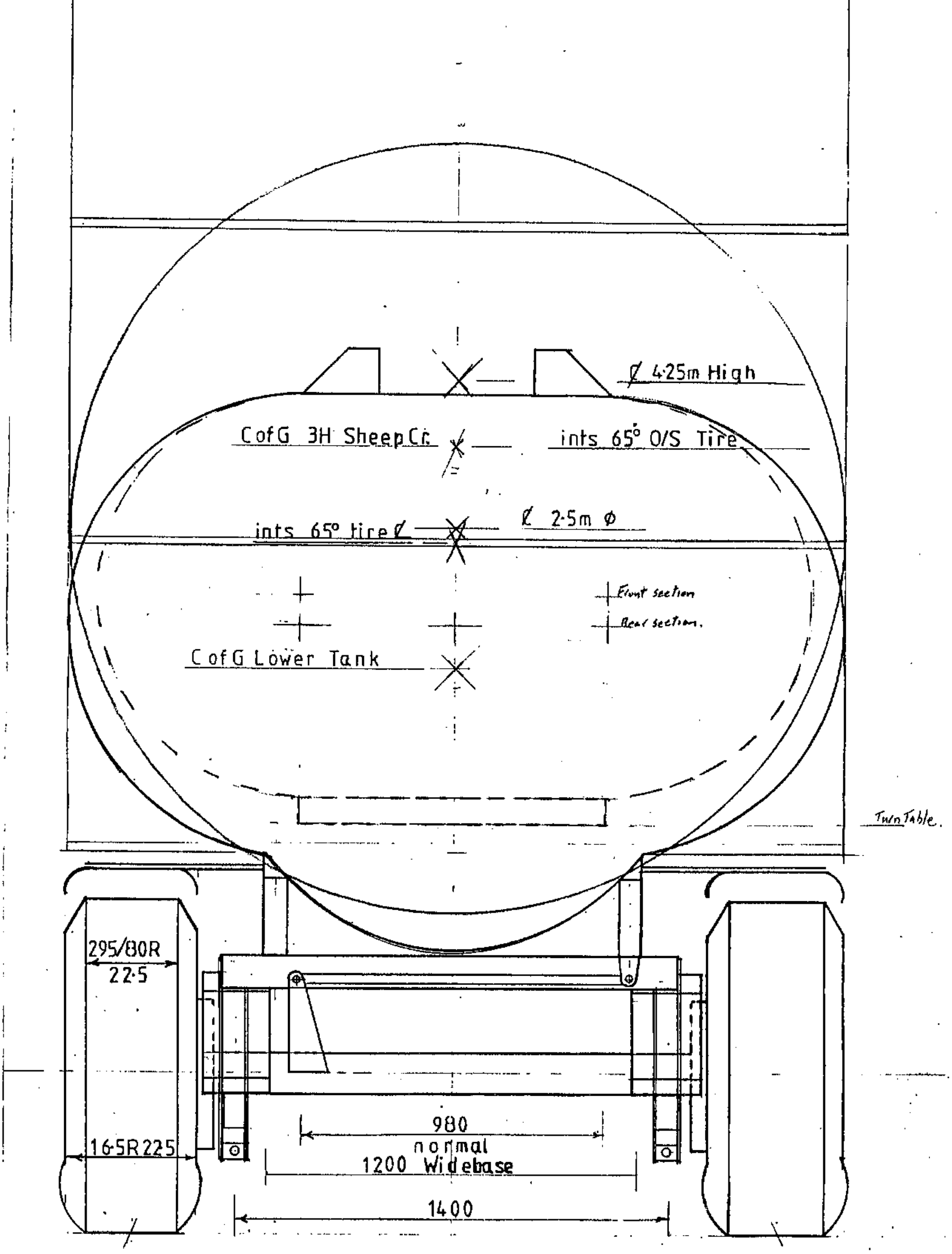




REVISIONS

REV.	DESCRIPTION	BY	DATE

APPENDIX E



TITLE	CONCEPT STABAX SUPER SIX		STABILITY SUSPENSIONS LIMITED
DRAWN	DATE 2 Dec 1986	SCALE	DWG. NUMBER
APPROVED	DATE	DEPT.	REV.