The Dynamic Stability Of Various New Zealand Vehicle Configurations

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ABSTRACT

Since 1987, DSIR has been undertaking extensive stability analysis of New Zealand heavy vehicle combinations by computer simulation.

Results of various studies have guided the Ministry of Transport (for example, in relaxing the minimum wheelbase requirement for trucks towing trailers from the proposed value of 5.5m to 4.25m) and individual clients.

Stability performance of a selection of typical New Zealand heavy vehicle combinations was determined. Most combinations meet the target requirements at maximum permissible mass, except for the 3-axle truck, 3-axle trailer.

Some of the pertinent findings obtained so far are outlined.

OVERVIEW OF PAPER

1.0 INTRODUCTION

Much of the recent development in heavy vehicle size and weight legislation has been based on factual or imagined stability differences between various combinations. For example, stability is the principal reason given by the Ministry of Transport for not increasing GCM (Gross Combination Mass) for A-trains or units with self-steering axles.

When the size and weight changes were proposed to the industry, the only basis for decisions on stability matters was overseas research findings. In fact, early proposals included phasing out of A-trains altogether!

Industry sources were critical of research results based on foreign vehicle dimensions and axle loads. Using vehicle dynamics software[1] obtained from UMTRI (the University of Michigan Transportation Research Institute), analyses of typical New Zealand vehicles have been undertaken by DSIR. This paper describes some of the results obtained to date from stability analyses conducted on New Zealand heavy vehicle combinations.

2.0 GENERAL RANKING OF NZ RIGS

2.1 NZ fleet

An analysis of general categories of New Zealand heavy vehicles was conducted to compare their stability performance. No effort was made to optimise the performance - this was a broad-brush approach to determine a general ranking of the various combinations.

The nine vehicle configurations selected for simulation were:

Combination	Abbreviation	
Tractor-semitrailer2	3-S2	(ie, 3-axle tractor, 2-axle semi)
Tractor-semitrailer3	3-S3	
B-train	3-S2-S2	
Truck-trailer33	3-3	
Truck-trailer34	3-4	
Truck-trailer43	4-3	
Truck-trailer44	4-4	
A-train1	3-S1-3	
A-train2	3-S2-2	

Details of each configuration are given in Appendix A. For performance comparison, most vehicle parameters were kept constant between combinations, such as suspension and tyre properties. The only parameters that were altered from one vehicle to the next were geometric (such as axle and hitch positions) and inertial (that is, mass distribution and axle loads) parameters. Tare masses appropriate to typical flat-deck units have been used throughout.

The centre of gravity (CG) heights of the unladen vehicles were also unchanged. To set the CG height of the load, a homogeneous load density of 545 kg/m^3 was assumed. The required payload which would load the axles up to the legal limits was fitted onto the available deck area. The height of the payload "box" was thus deter-

[1] IRTENZ funded the purchase of this UMTRI software.

mined and the payload CG height evaluated. Assuming a standard deck height of 1.4m, the payload CG heights were typically 2.0m above the ground.

Details of the performance measures and evaluation methods are given in Appendix B.

2.2 Results

Figures 1 to 3 summarise the stability results for typical New Zealand vehicles operating at the new size and weight limits. The results indicate that the Ministry of Transport has done reasonably well in determining which combinations are permitted higher GCMs, for general cartage. The notable exception is the 3-axle truck, 3-axle trailer combination, (abbreviated to 3-3) which does not meet the target value for Dynamic Load Transfer Ratio. This matter requires further investigation to ascertain the factors affecting its stability, and to provide design guide-lines to maximise stability.

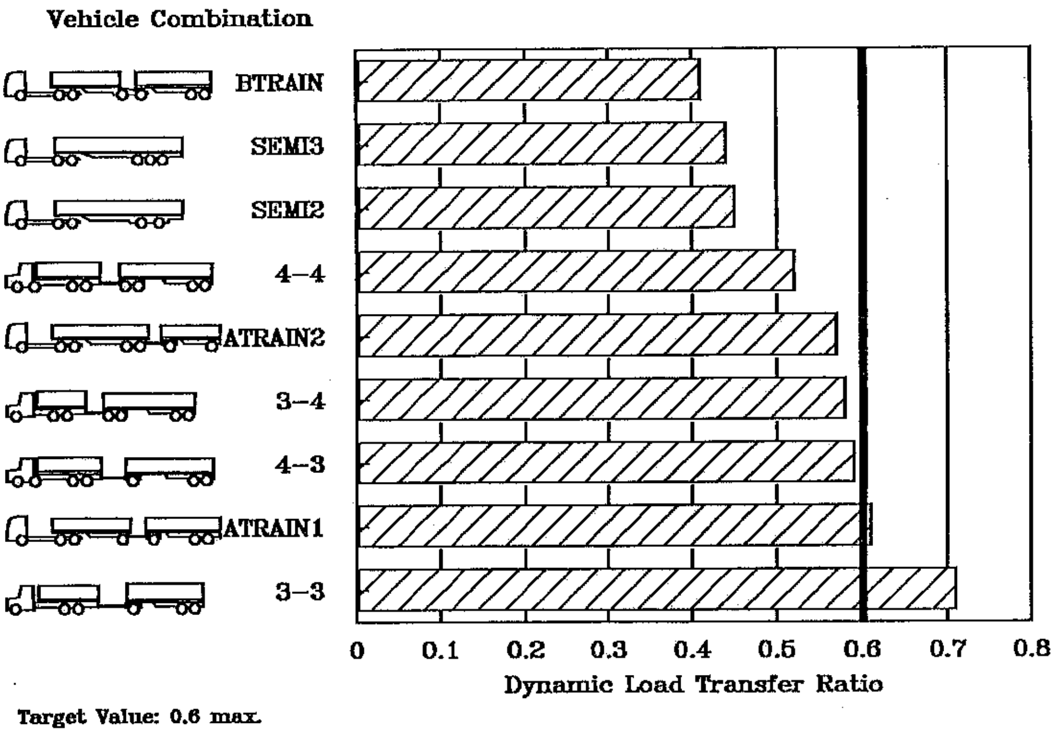

Figure 1.
Dynamic Load Transfer Ratios
Results for various New Zealand heavy vehicle combinations

The target values are derived from those proposed in the Roads and Transportation Association of Canada (RTAC) stability review [1][2]. Despite our 2.5m width limit (compared with Canada's 2.6m), New Zealand vehicles compare favourably with the Canadian results in the dynamic high-speed manoeuvre. However, because of the different width limit, a Static Roll Threshold of 0.35g is considered to be a more reasonable and equivalent target for New Zealand vehicles (compared with 0.40g used in the RTAC review). Since slosh effects are not yet taken into consideration during the stability analysis, a Static Roll Threshold of 0.40g is used for New Zealand tanker vehicles.

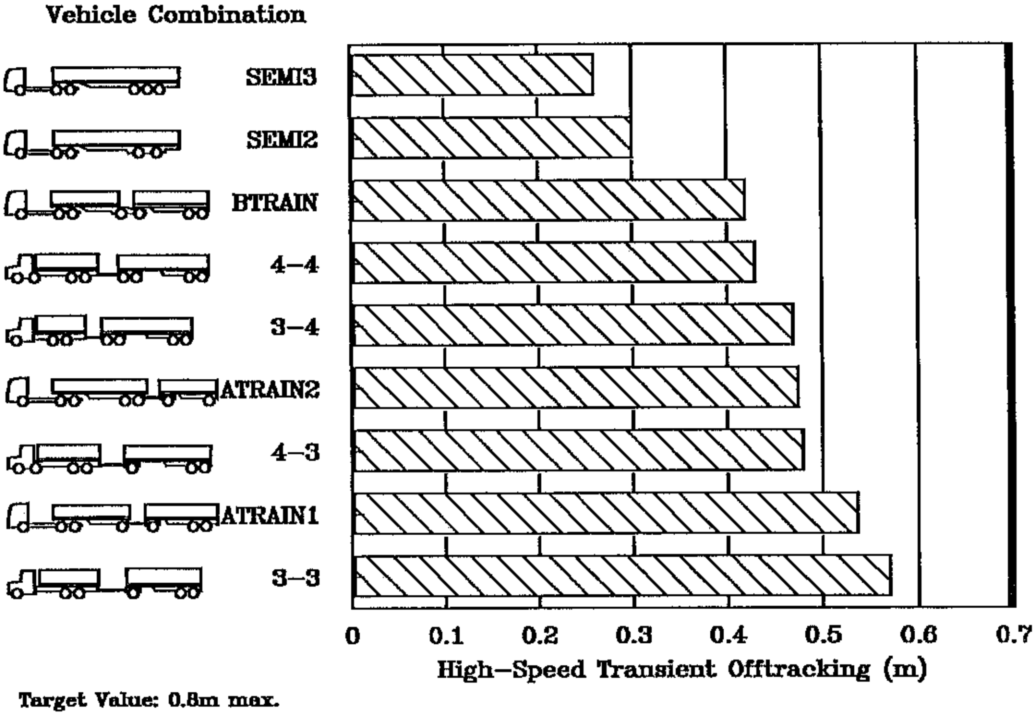

Figure 2.
High-speed Transient Offtracking
Results for various New Zealand heavy vehicle combinations

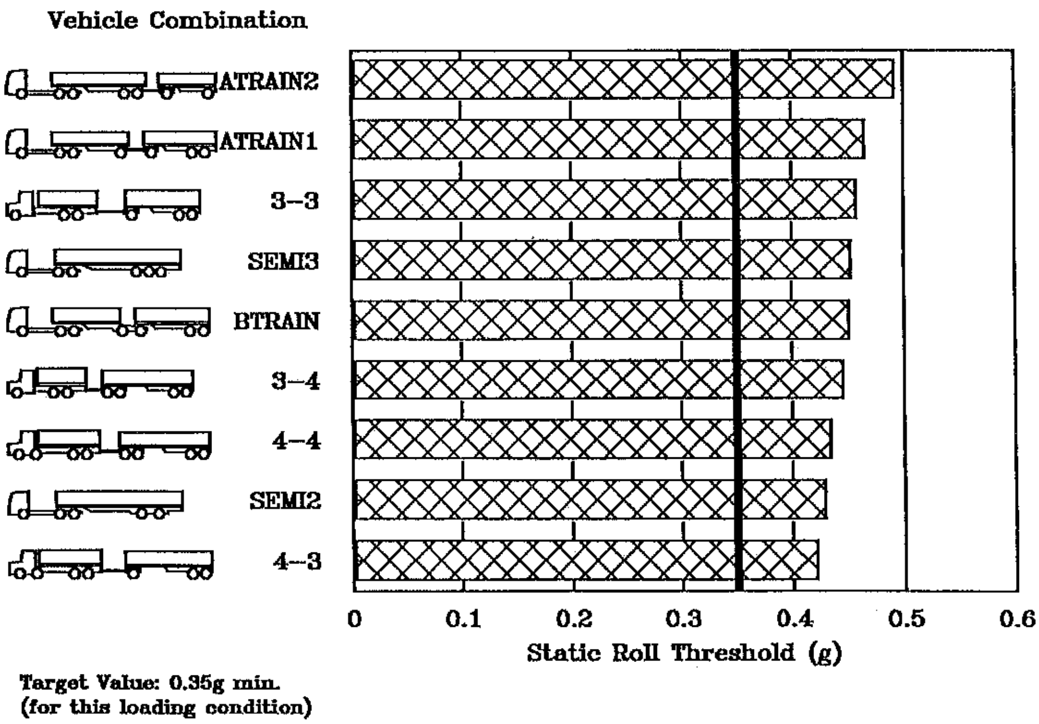

Figure 3.
Static Roll Threshold
Results for various New Zealand heavy vehicle combinations

3.0 SPECIFIC INVESTIGATIONS

3.1 Milk Tankers

Dairy companies generally require A-trains for milk collection because of their superior manoeuvrability in negotiating restricted farm accesses. Some dairy companies are keen to be permitted 44t on A-trains (up from the present limit of 39t).

Figures 4 and 5 indicate the variation in stability between general-purpose and special-purpose A-trains at 39 and 44 tonne GCM.

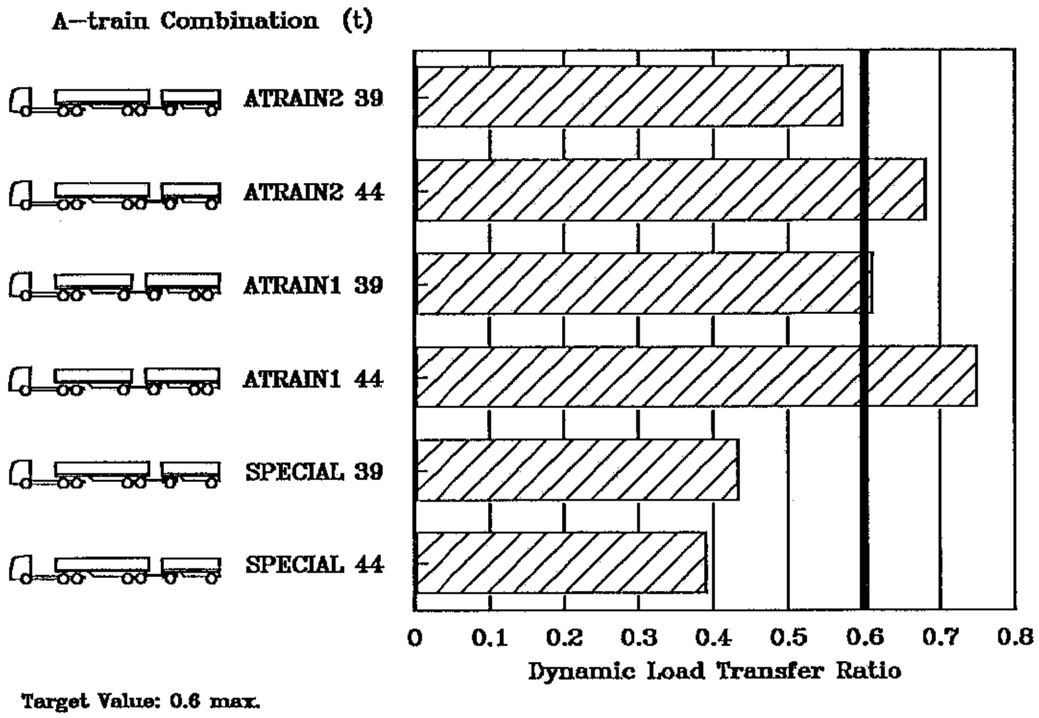

Figure 4.
Dynamic Load Transfer Ratios for various New Zealand A-trains

The Dynamic Load Transfer Ratio results indicate that 44t A-trains are inappropriate for general cartage (this is evident from the Dynamic Load Transfer Ratio results. The "special purpose" A-trains, on the other hand, exhibit very good stability, such that, even at 44t GCM they meet the performance targets. This is principally due to their lower CG, optimised suspension parameters (such as roll stiffness and roll centre height), minimised drawbar hitch overhang and attention to weight distribution. That careful design is necessary is indicated by the fact that none of the existing milk collection A-trains which were simulated met the dynamic stability targets [3].

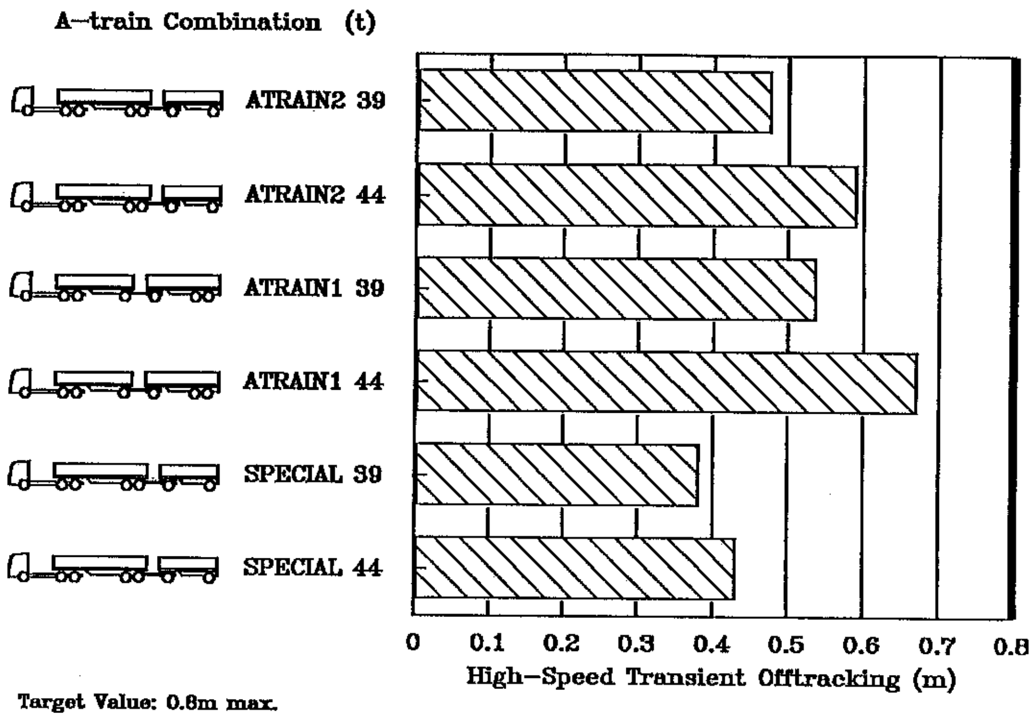

Figure 5.
High-speed Transient Offtracking
Results for various New Zealand A-trains

For milk collection vehicles, however, increasing Gross Combination Mass is not necessarily the most cost-effective option. Minimising tare mass was identified as one sure method to reduce transport costs.

3.2 Minimum Truck Wheelbase

A minimum truck wheelbase of 4.25m for 3-axle trucks in a combination exceeding 39t has been introduced. This was not a clear requirement from stability considerations, although handling performance was found to be degraded as truck wheelbase was shortened. The 4.25m dimension was agreed to by the Ministry of Transport and New Zealand Road Transport Association as a desirable minimum. Originally, the minimum truck wheelbase was proposed by the Ministry of Transport to be 5.5m.

A study undertaken by DSIR compared the stability of a range of twelve 6x4 truck-trailer combinations with different truck wheelbases. The configurations were as specified by the Ministry of Transport and the New Zealand Road Transport Association. Details of the twelve vehicle configurations simulated and the results obtained are given in the report to the Ministry of Transport [(4)].

Additional simulations examined the effect of altering the CG height of the load and the influence of drawbar hitch overhang (the distance from the rear axis to the coupling). The stability of the unladen combinations were also investigated.

The investigation revealed that:

1. In general, longer truck wheelbase is associated with higher dynamic load transfer ratio (experienced by the trailer), and therefore lower combination stability.
2. Dynamic load transfer ratio improves with lower laden CG height.
3. Shifting the drawbar coupling position forward directly improves the performance of the trailer. This is evident from a reduction in the dynamic load transfer ratio, high-speed transient offtracking and rearward amplification. The behaviour of the lead vehicle is essentially unchanged.
4. Four-axle trailers are more stable than three-axle trailers of equivalent deck length when compared behind the same truck.

Observations (2), (3) and (4) are as anticipated. The first point, however, requires an explanation. It is believed that the combined effect of a relatively long drawbar hitch overhang, short drawbar and short wheelbase of the trailer units is the dominant cause of the poorer stability of the long truck/ short trailer combinations.

It was not possible, from the investigation, to categorically state the minimum desirable truck wheelbase for truck-trailer combinations. The combinations with shorter truck wheelbases performed worse in the handling simulations, but this is the case whether or not a trailer is attached. Due to the overall length constraints, longer truck wheelbases are associated with short trailer wheelbases. This situation also appears to be suboptimal, as rearward amplification increases with shorter trailer wheelbases, resulting in poorer stability performance.

The study concluded that a definitive technical basis for proposing a minimum truck wheelbase for truck-trailer combinations could not be given, although the trends found indicate that truck and trailer wheelbases towards the middle of the range examined (that is, 4.5 to 5.5m) are more desirable.

3.3 3-4 Units

A group of operators of 3-4 units (3-axle trucks and 4-axle trailers) sought an increase in the permitted GCM for 3-4 units from 42t up to 44t.

Analyses were undertaken to compare the stability of several 3-4 truck-trailer units (operating at 44 tonne GCM and 20 metre overall length) with a number of other typical heavy vehicle combinations to assess their relative performance. Details of the configurations, simulation conditions and results are given in the DSIR report(5) to the group of operators who commissioned the investigation (*Road Transport Research*).

The Dynamic Load Transfer Ratio performance of typical 3-4 and 4-3 units are compared in Figure 6.

Some of the conclusions reached from the research were that:

1. The stability performance of typical 3-4 truck-trailer units at 44t is on a par with typical 4-3 units (which are already allowed 44t).
2. Doubts were raised regarding the stability of 3-3 units operating at 42t GCM.Economic analyses of the benefits and costs to the nation of these proposed changes were undertaken by a consultant team to support the technical arguments to the Ministry of Transport. Significant net transport cost savings could be realised if the changes were approved in the case of 3-4 truck-trailer units.

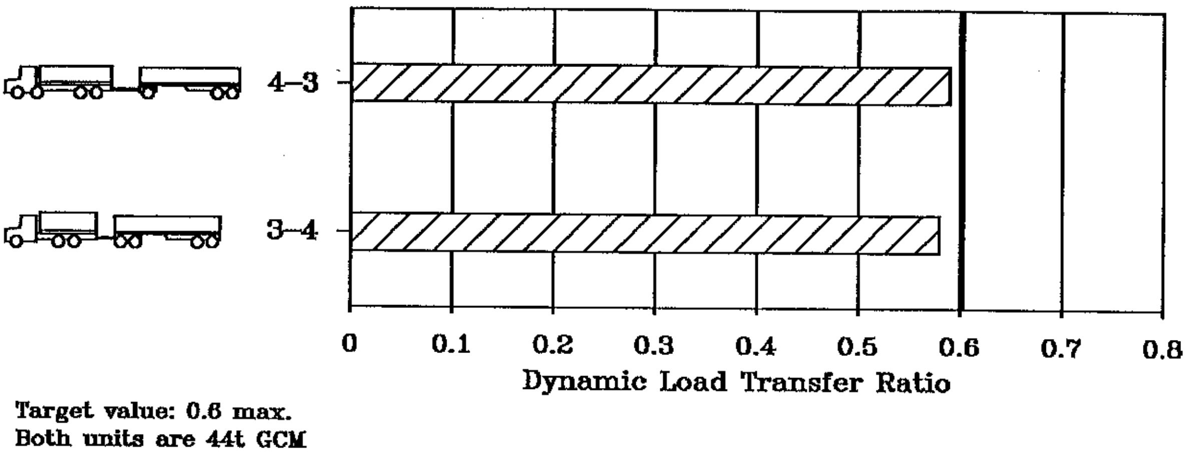

Figure 6.
Dynamic Load Transfer Ratio
Performance of Typical 7-Axle Truck-Trailers

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3.4 Parametric effects

3.4.1 CG Height

It cannot be stressed too highly that CG height has a dominant effect on vehicle stability. All other parameters (except vehicle width, which is controlled by law) have only secondary effects. Thus, all reasonable steps should be taken to minimise deck height.

3.4.2 Hitch Position

Minimising the distance from the rear axis to the coupling (the drawbar hitch over-hang) is found to have a significantly beneficial effect on dynamic stability.

3.4.3 Wide Single v Dual Tyres

Wide single tyres allow the distance between suspension springs to be increased. If this advantage is utilised, then vehicles with wide single tyres exhibit improved roll stability. This would be evident in both the Static Roll Threshold and Dynamic Load Transfer Ratio performance measures.

However, this is gained at the expense of increased Transient High-Speed Offtracking. Thus, from stability considerations, low CG A-trains are better off with dual tyres (to enhance their marginal Transient High-Speed Offtracking), while a combination with marginal Dynamic Load Transfer Ratio would be improved with wide single tyres and increased spring bases.

3.4.4 Low Profile Tyres

Low profile tyres offer two stability advantages over standard tyres:

- the smaller rolling radius lowers the vehicle CG by a small amount (the magnitude of the reduction was not found to make a significant difference); and
- the shorter sidewalls contribute to increased cornering stiffness and hence greater overall stability.

4.0 FURTHER WORK

4.1 3-3 Truck-Trailer Units

As already noted, there is need for further investigation into the dynamic stability of 3-3 units. The factors affecting its performance at 42t GCM need to be determined, and design guide-lines produced to aid in the attainment of stability targets.

4.2 Parametric studies / Optimisation

Similarly, there would be benefit in conducting equivalent parametric studies for other vehicle configurations, particularly those of inferior initial stability.

4.3 Self-steering axles

A research program is underway for the Ministry of Transport to investigate the stability of triaxle semi-trailers with one self-steering axle.

4.4 Alternative dollies

Drawbar configurations are available which significantly enhance the dynamic stability of A-trains and truck-trailers [(6)]. These would be worth investigating to determine which types would be suitable for New Zealand, particularly in view of our Drawbar Standard requirements.

4.5 Slosh

Currently, we do not have the resources to include slosh effects in the stability investigations. Some overseas research organisations [(7),(8)] are tackling this issue. We will keep up-to-date with their progress and implement their findings where appropriate.

5.0 CONCLUSIONS

The target stability performance values employed by DSIR appear to be reasonable. New Zealand combinations at current size and weight limits generally meet the stability targets. Tractor-semitrailers and B-trains exhibit very good stability characteristics. Truck-trailers and A-trains are inferior, but acceptable. The exception is a typical 3-3 truck-trailer units operating at 42t GCM. Their stability is cause for concern, as it does not meet the target requirements. Further research into the stability of 3-3 units is recommended.

The stability of typical 4-3 and 3-4 truck-trailer units are comparable and acceptable at 44t GCM. There is, therefore, no reason with respect to vehicle stability to restrict 3-4 units to the present 42t GCM limit. Instead, for stability reasons, it would be prudent to encourage the use of 3-4 units (by relaxing the GCM limit to 44t), rather than favour 3-3 units (which do not typically meet all stability performance targets and currently enjoy a payload advantage over 3-4 units).

It has been demonstrated that A-trains can be stable at 44t GCM. This applies only to special-purpose units designed for particular applications. This does not apply to most current A-trains.

The proposed requirement for a minimum truck wheelbase of 5.5m for certain combinations was relaxed following an investigation into the stability performance of a range of truck-trailer units.

There is scope for further stability improvement in most New Zealand heavy vehicle combinations.

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(5) White, D.M. *The Stability of 3-4 Truck-Trailer Units in Comparison with Various Heavy Vehicle Combinations,* DSIR Report 71501632 to Road Transport Research, May 1989.

(6) Winkler, C.B. *Innovative Dollies: Improving the Dynamic Performance Of Multi-Trailer Vehicles*, Int. Symp. on Heavy Vehicle Weights and Dimensions, Canada, 1986.

(7) Tso, Y. Australian Road Research Board, Personal Communication, 1988.

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APPENDIX A

DETAILS OF NEW ZEALAND VEHICLE CONFIGURATIONS SIMULATED

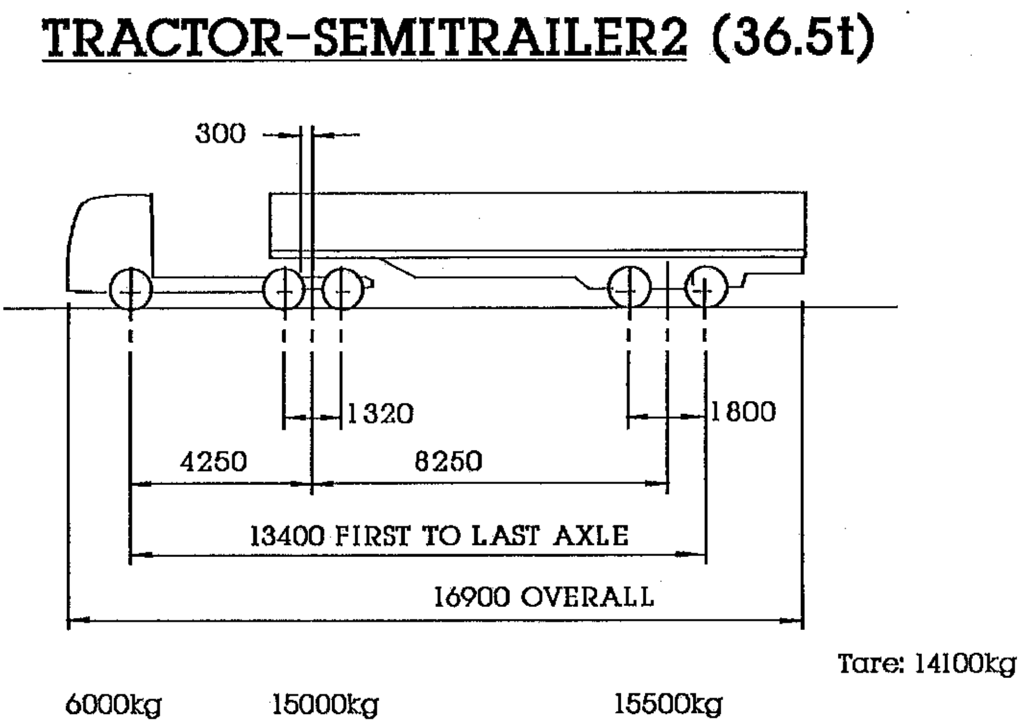


Figure A-1

TRACTOR-SEMITRAILER3 (39t)

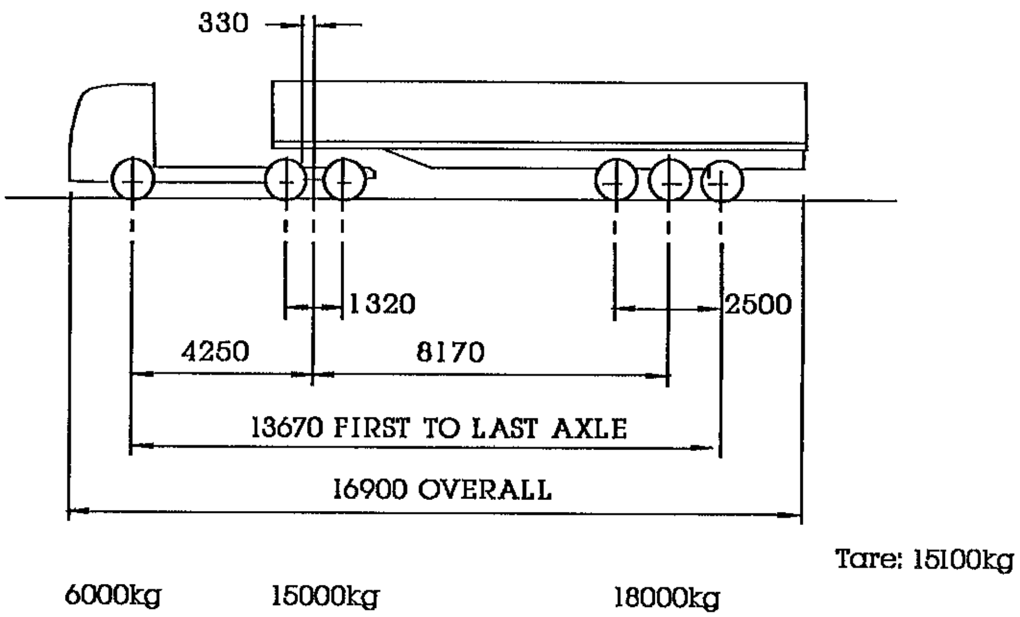


Figure A-2

B-TRAIN (44t)

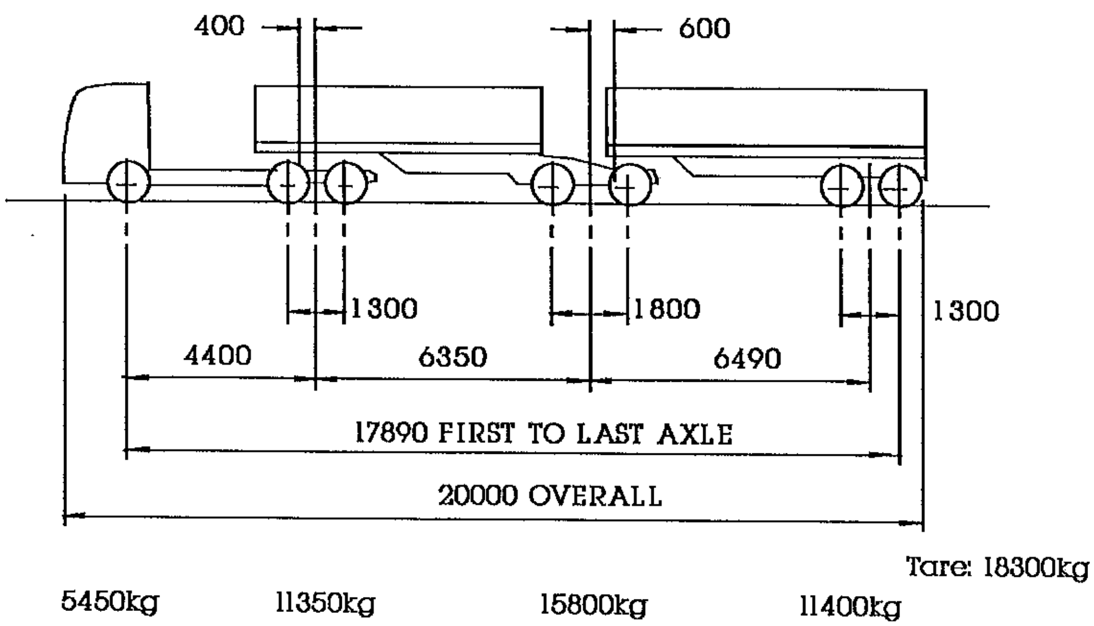
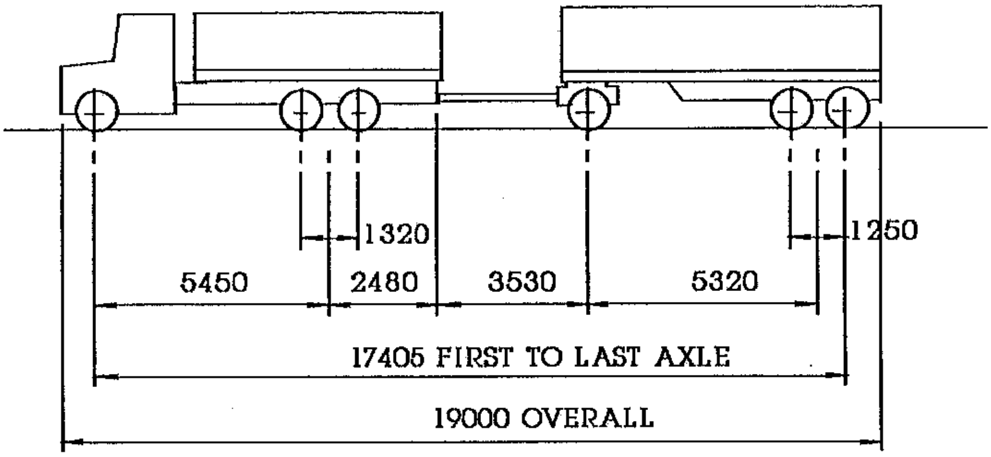


Figure A-3

TRUCK-TRAILER 3-3 (42t)

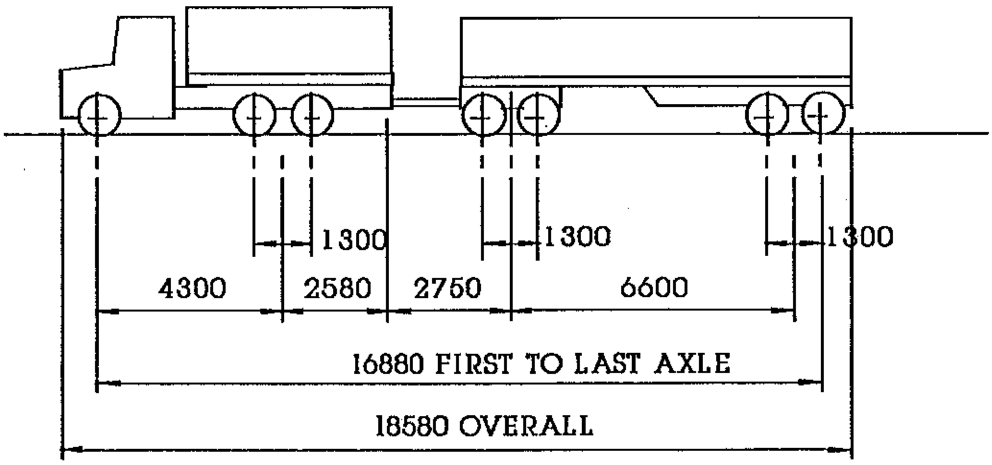


Tare: 16000kg

6000kg 15000kg 8200kg 12800kg

Figure A-4

TRUCK-TRAILER 3-4 (42t)

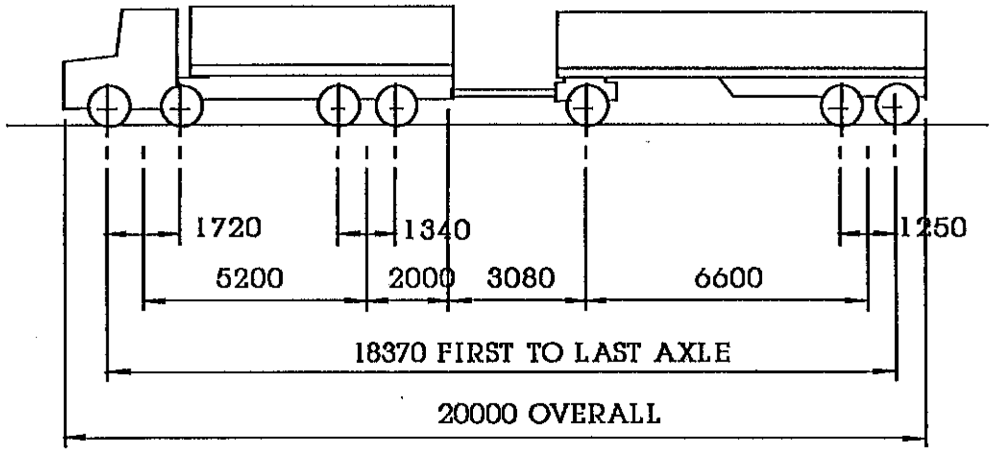


Tare: 17000kg

6000kg 14500kg 11300kg 11300kg

Figure A-5

TRUCK-TRAILER 4-3 (44t)

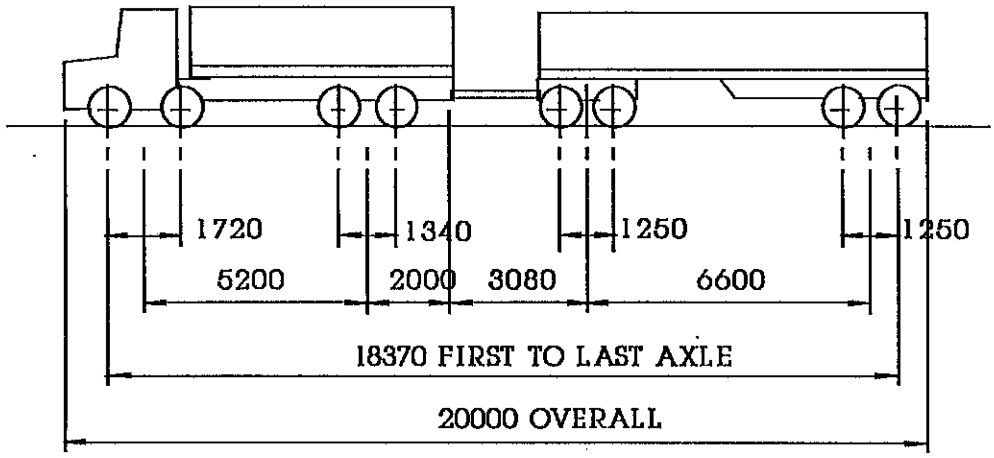


Tare: 17300kg

9500kg 14000kg 8200kg 12300kg

Figure A-6

TRUCK-TRAILER 4-4 (44t)



Tare: 18300kg

9300kg 14200kg 10600kg 9900kg

Figure A-7

A-TRAIN1 (39t)

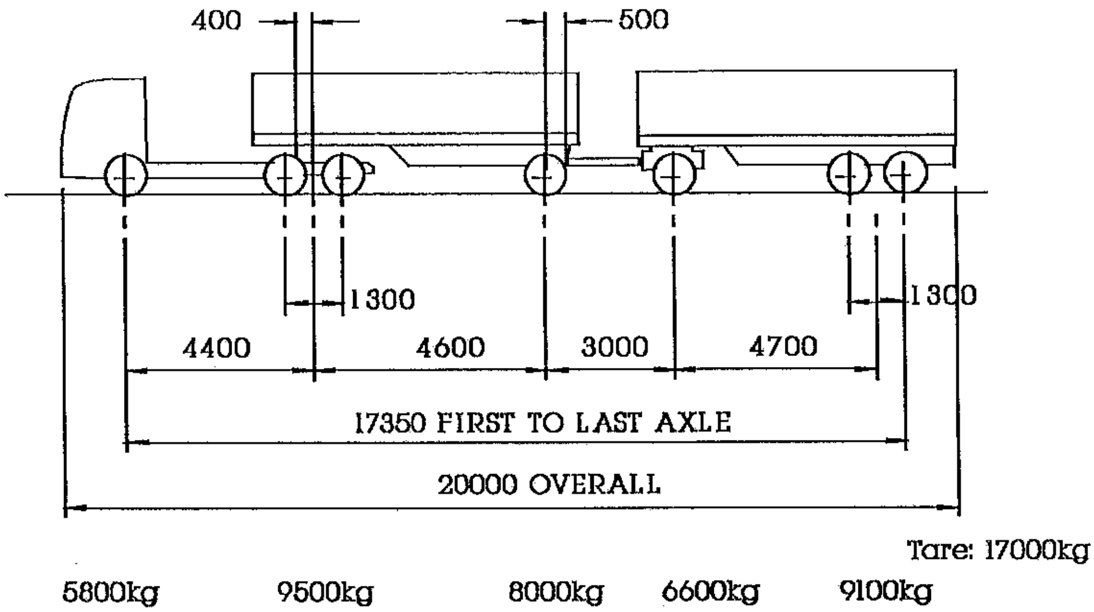


Figure A-8

A-TRAIN2 (39t)

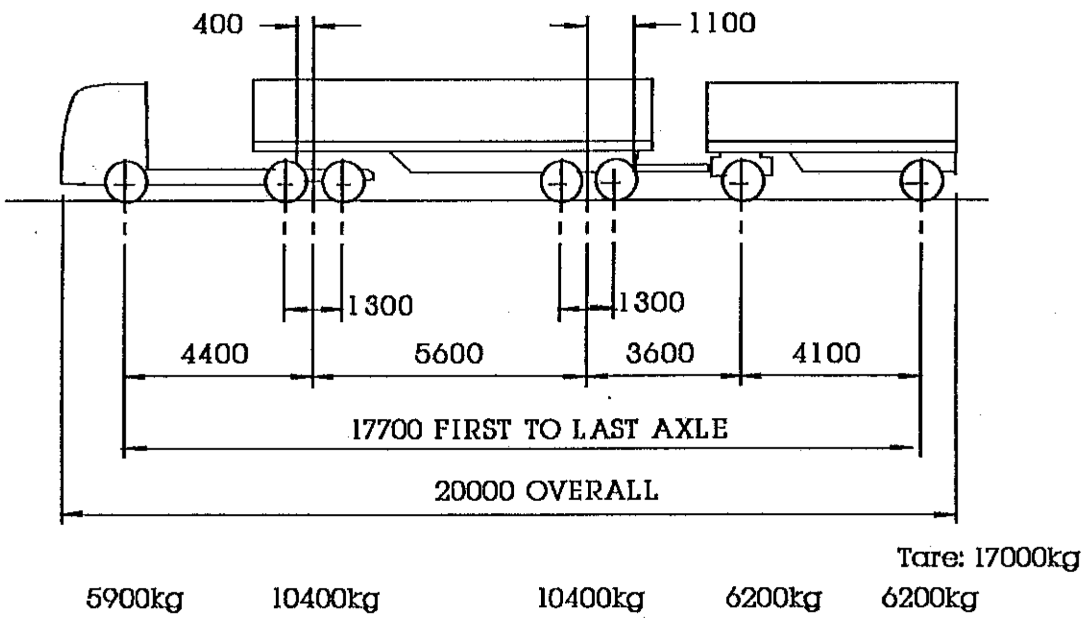


Figure A-9

APPENDIX B

PERFORMANCE MEASURES, TARGET VALUES AND EVALUATION METHODS

B.1 Static Roll Threshold

The Static Roll Threshold is the maximum level of steady lateral acceleration a combination can tolerate without overturning one or more units (usually expressed in 'g', where 'g' is the acceleration due to gravity). A quasi-steady turn with slowly increasing steer angle was simulated to determine the Static Roll Threshold.

The international consensus amongst vehicle dynamics experts for a desirable performance level is 0.40g steady state lateral acceleration without overturning. This view is expressed in publications from Australia (Mai & Sweatman, 1984), Sweden (Strandberg, et al, 1975), Canada (Ervin & Guy, 1986) and the United States (Ervin, et al, 1980).

In Canada the maximum width permitted is 2.59m. Many New Zealand vehicles, like their U.S. counterparts, would have difficulty in meeting a 0.40g target while the width limit is 2.50m. It also explains why the Australian and U.S. researchers limited the 0.40g target to vehicles transporting hazardous liquid loads only, rather than the whole heavy vehicle fleet. (The width limit in Sweden is 2.60m.)

Consequently, 0.4g does not appear to be a reasonable target for New Zealand vehicles in general cartage. It could be used, perhaps, for vehicles carrying dangerous goods or shifting loads (such as liquids). While any improvement in Static Roll Threshold is desirable, since research shows that this greatly reduces the incidence of overturning accidents, it appears that a realistic target would be 0.3g for a cube-out, gross-out homogeneous load condition up to the legal height limit. This is easy to determine, unlikely to be exceeded in practice, and compares favourably with the 0.33g roll stability requirement for dangerous goods vehicles.

Alternatively, or additionally, with a homogeneous load of 545 kg/m^3 which is typical of general freight, 0.35g is proposed as a target for Static Roll Threshold.

B.2 Handling

When considering steady turning, "handling" refers to the response of the towing unit to steering inputs. A steady turning case with gradually increasing steer angle at a constant forward speed of 88.5 km/h was simulated. Two performance measures are given: steering sensitivity, and critical velocity, both determined at 0.3g lateral acceleration.

Steering Sensitivity is a performance measure indicating the margin of directional stability. If the steering sensitivity is zero or less, the vehicle is unstable. Without continuous, highly-skilled steering adjustments (similar to a rally driver applying opposite lock in a sharp corner), the vehicle will probably spin out of control.

If the vehicle exhibits directional instability below its roll-over threshold, then the critical velocity is the speed at which instability commences. A stability envelope can be constructed beyond the bounds of which the vehicle will become unstable.

B.3 Dynamic Load Transfer Ratio

This is an expression of dynamic roll stability, and is defined as

$$\text{Dynamic Load Transfer Ratio} = \frac{FZL - FZR}{FZL + FZR}$$

where FZL = sum of all vertical tyre forces along the left hand side of the vehicle (except the steer axle), and

FZR = the corresponding sum for the right hand side.

Travelling on a straight, level road a vehicle will have a Dynamic Load Transfer Ratio of 0.0. At the limit when all wheels on one side of the vehicle lift the Dynamic Load Transfer Ratio is 1.0. Dynamic Load Transfer Ratio thus indicates how near a vehicle is to its overturning limit.

For units which are entirely roll-coupled the load transfer ratio is calculated over the entire combination. For truck-trailers the Dynamic Load Transfer Ratio is determined separately for the trailer and the truck. This is because they are not roll-coupled - one portion of the combination can overturn without the other.

Ervin and Guy (1986) in devising this performance measure suggest 0.60 as a maximum for a vehicle during a rapid path change manoeuvre of this type.

B.4 Transient High-Speed Offtracking

Offtracking is the lateral offset of trailer axle paths with respect to the path of the tractor steer axle. Transient High-Speed Offtracking is a measure of the maximum offtracking which occurs during a rapid path change manoeuvre at highway speed.

The significance of transient high-speed offtracking is that the difference in path may be sufficient to cause the final trailer to encroach on the path of another road user, or for one or more wheels to leave the road, risking a "tripping" roll-over incident.

A performance target of 0.80m is nominated by Ervin & Guy (1986) who originated this measure. Their basis for selecting 0.80m was that it represented the mid-level of the Canadian vehicles examined (which included A-, B- and C-train doubles and triples all simulated for 100km/h forward speed).

The dynamic manoeuvre selected for simulation was such that it resulted in a cyclic lateral acceleration of 0.15g imposed on the truck C.G. The manoeuvre had a period of 2 or 3 seconds, whichever was found to be the worst case for the vehicle combination. Dynamic Load Transfer Ratio and Transient High-Speed Offtracking were continuously evaluated by the computer simulation throughout this manoeuvre and the maximum values noted.