VEHICLE STABILITY
AN OVERVIEW

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ABSTRACT

The New Zealand road transport industry must improve its road safety record. Road transport engineers' contribution to road safety is predominantly through designing, constructing and maintaining inherently safe vehicles. Stability is an important factor to be considered. Instability can take several forms: trim stability, steering control, trailer fidelity, rollover, jackknife and trailer swing. Methods exist for assessing vehicles for these various types of instability.

1. INTRODUCTION

Accident statistics show heavy goods vehicles to be overrepresented in fatal accidents. Of all road injury accidents, sixty percent (1) could be avoided by applying proven countermeasures (Figure 1.1). Of this avoidable 60%, it is estimated that 15%, 20% and 25% could come from measures applied to the road, vehicle and driver respectively. An OECD report (2) indicates that vehicle stability, manoeverability and emergency braking are important factors in 20 to 25% of accidents involving heavy vehicles.

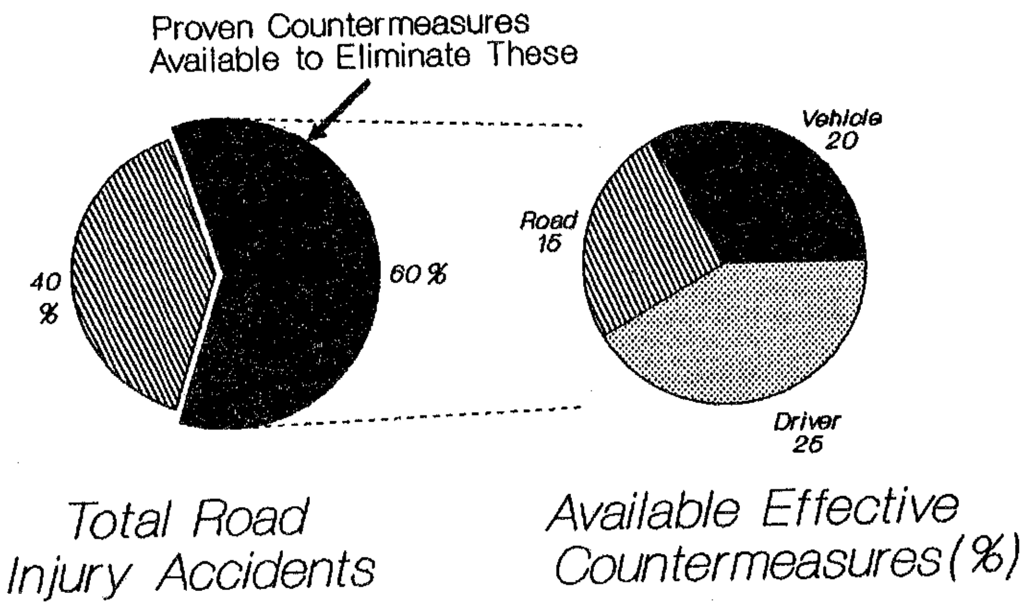

Figure 1.1
Scope for Road Safety Improvement

Vehicle factors are divisible into three categories:

(a) Technical Defects / Poor Maintenance;
(b) Technical Design Inadequacies;
(c) Passive Safety Measures.

1.1 Technical Defects / Poor Maintenance

This is a causative factor in typically 5% of accidents. Some examples are defective brakes, tyre blowouts, mechanical failures, coupling defects and structural failures.

1.2 Technical Design Inadequacies

These deficiencies are commonly inherent in current prime mover and trailer design and construction. Consequently they are amenable, to varying degrees, to improvement by research and development. The main areas identified in the OECD report (2) were:

> "(a) low resistance to rollover;
> (b) poor road keeping in curves;
> (c) low lateral stability during braking;
> (d) insufficient braking power;
> (e) weak turning signal lights;
> (f) lack of rear reflective markings:
> (g) reduced rear view in the near field."

1.3 Passive Safety Measures

Certain devices reduce the severity of a crash. Their presence or absence is not normally a contributory factor to an accident. Seatbelts and cab impact strength standards enhance the vehicle occupants' safety, while efforts to reduce the vehicle's aggressivity, such as underrun protection, improve the safety for other road users.

1.4 Safety Responsibility of Heavy Road Transport Industry

Most enterprises in New Zealand are conducted on private property. Yet numerous regulations regarding safety are enforced to ensure personnel are not endangered by various business operations. Road transport is undertaken almost totally in the public domain. The New Zealand road network, despite criticisms of its quality and the size of road user charges, is a public asset, to be shared with other legitimate road users. The general public (many of whom are abysmal drivers and should not be allowed on the public roads) are nevertheless entitled to question why heavy vehicles are overrepresented in fatal accidents, and what steps are being taken to improve overall road safety. While commercial road transport serves a vital function, to quote Mr Ervin (3),

> "the very operation of trucking [is] contingent upon the public trust which has been tacitly placed in allowing a commercial enterprise to conduct its business on that which is owned, occupied and maintained publicly."

Truck manufacturers, trailer manufacturers, operators, drivers, legislators and researchers must recognise that there is still much to be done to reach basic levels of safety for heavy goods vehicles.

2. TYPES OF VEHICLE INSTABILITY

A definition of "vehicle stability" is the combination of vehicle properties which allows a typical driver to maintain easy control of the vehicle in all intended and foreseeable driving conditions.

Control is the application of inputs (steering, braking and acceleration) to keep the vehicle or vehicle combination on the desired path at the desired speed. Feedback to the driver is important for him to know whether the desired trajectory and speed are being maintained or, more importantly, whether urgent corrective action is required to avoid total loss of control. In a vehicle, feedback is limited to visual information (including from mirrors and instruments) and tactile sensations, that is, "feel" through the steering wheel, control pedals and the "seat of the pants".

Thus, "instability" can be defined as the unexpected response of a vehicle such that control is marginal or lost altogether.

For heavy goods vehicles stability problems can exist in any of three regions of interest (4):

(a) Trim Stability. This is the classical stability sense of a system returning itself to an equilibrium position after a small disturbance, such a wind gust or road bump.

(b) Handling. The controllability of a vehicle during typical driving manoeuvres.

(c) Limit Performance. The behaviour of a vehicle when driven in extreme manoeuvres, such as attempting to avoid an obstacle.

Specific instability problems are thus:

1. Trim Stability
2. Steering Control
3. Trailer Fidelity
4. Rollover
5. Jackknife / Trailer Swing

These are each discussed below.

3. TRIM STABILITY

3.1 Description

Instability in this mode is most commonly exhibited as an oscillatory motion of a vehicle combination travelling at highway speeds (car-caravan combinations are particularly susceptible), although aperiodic behaviour is also theoretically possible. Despite the fact that oscillations may be small enough for the driver to retain control, the motion arouses concern amongst other road users.

As the number of units in a vehicle train increases there are a greater number of modes of oscillation, any one of which could become unstable. Thus, trim stability analysis is important for A-trains, B-trains, truck-trailers, and for semitrailers with self-steering bogies.

3.2 Method of Assessment

The usual approach is to formulate the equations of motion of the vehicle units and solve the characteristic equation for the stability roots. Negative real roots are stable. Positive real roots are unstable.

Jindra (5), for example, conducted a simple, analytical assessment of tractor-semitrailer stability. Figure 3.1 is a metric version of his assessment of the stability of an 18 tonne tractor-semitrailer. His investigations showed that increasing the kingpin to semitrailer axle distance enhances stability, but shifting the fifth wheel position behind the tractor rear axis leads to divergent unstable motion.

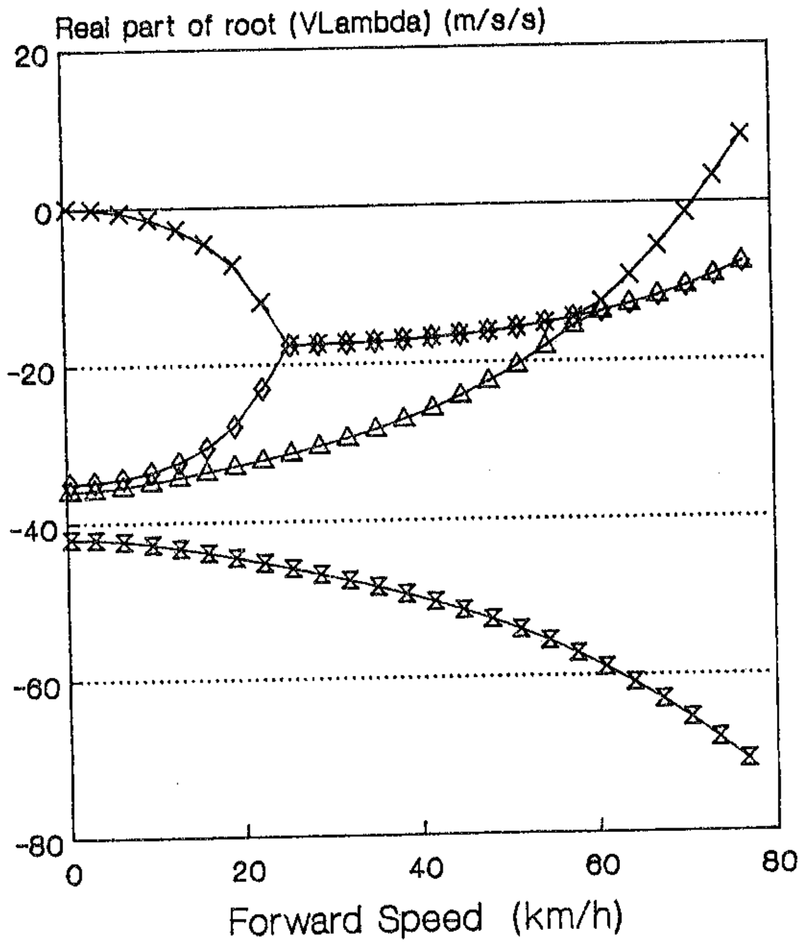

Figure 3.1
Roots of Characteristic Equation, indicating Stability. from Jindra (5)

4. STEERING CONTROL AND TRAILER FIDELITY

4.1 Description

Certain driving inputs (steering, braking, acceleration) are required to cause a vehicle combination to follow a desired trajectory at a certain speed. Steering control analysis indicates what demands are placed on the driver of a dynamically complex vehicle when undertaking typical manoeuvres, and the response of the vehicle combination. It has already been mentioned that the driver has very limited feedback from the trailing units of his vehicle. This constrains somewhat his ability to respond to a difficult situation and thus is an important factor in the controllability of the combination.

Tractor-semitrailers commonly exhibit oversteering characteristics, that is, for an increase in speed in a corner, less steer angle is required. Mr Ervin of UMTRI (University of Michigan Transportation Research Institute) described tractor yaw stability in some depth at the previous IRTE seminar (6).

At the same gathering he also discussed trailer offtracking and rearward amplification. Offtracking is the behaviour of trailers in tracking inboard of the prime-mover in low-speed turns, and outside the trajectory of the prime-mover when cornering at highway speeds.

4.2 Rearward Amplification

Rearward amplification is included in this section because, while it can commonly result in rollover of one or more trailers, it is in itself a steering control problem and is examined in the same manner.

Rearward amplification is a phenomenon found with some multiply-articulated vehicles. It can occur when the driver makes a rapid steering movement, typically at highway speed. This need not be a lane-change - that is merely a common manoeuvre selected for full-scale testing - but could also occur when swerving to avoid an obstacle or an unpredictable road user, or when quickly pulling back onto the road after drifting on to the shoulder. The rapid steering input results in a "crack the whip" situation: the lateral acceleration at the final trailer can be more than three times that experienced by the tractor unit. This may be sufficient to roll the trailer. One fleet accident investigation in USA (3) noted that 60% of the company's A-train rollover accidents were of the final trailer only. The most influential items with regard to rearward amplification are the trailer couplings. Overseas studies indicate that A-trains have serious rearward amplification problems. The B-train was developed to resolve this problem, but it is recognised that there are manoeuverability constraints and added difficulties in hitching and unhitching trailers. The C-train is now being developed to possess the desirable characteristics of both configurations (7).

4.3 Methods of Assessment

Steady-state steering control behaviour can be examined analytically using an approach similar to the trim stability analysis. Equations can be written to describe the steer angle, and articulation angle/s as a function of speed in a steady turn.

The linear system can also be subjected to a spectrum of sinusoidal steer inputs to determine the response of the vehicle combination (8). This reveals the extent of rearward amplification.

Non-linear digital computer programs for multi-degree-of-freedom systems, such as the UMTRI Stability Software, enable the simulation of complex manoeuvres with accurate representation of intricate vehicle components, such as couplings, steering, brakes and tyres.

Full-scale testing can also highlight steering control problems, though New Zealand lacks appropriately sized test areas for heavy goods vehicles (the best sites are reserved for the transportation by air of international passengers and freight!). Suitable safety precautions such as outriggers and anti-jackknife cables may be required.

5. ROLLOVER

5.1 Description

Rollover is the most easily identified, and probably the most important vehicle stability issue. In the USA it has been estimated that rollover is involved in 4-9% of all medium and heavy vehicle accidents, and occurs in approximately one-third of the single vehicle injury accidents (3). The graph presented at the last seminar by Mr Ervin illustrates the sensitivity of the incidence of rollover (as a proportion of single vehicle accidents) to rollover threshold (Figure 5.1).

The main ways to improve rollover threshold are to use wider vehicles, to lower the centre of gravity (CG), and to optimise suspensions. The sensitivity of rollover to various vehicle factors is illustrated by the following examples (10).

A change from 36 to 39 tonne for 5-axle tractor-semitrailers results in an estimated 25% increase in the incidence of rollovers in single vehicle accidents. This assumes that the vehicle stays the same except for the increased weight and hence in increased volume and CG height. Similarly an increase in vehicle width from 2.44m to 2.59m could reduce the incidence of rollovers in single vehicle accidents by 35%. On the other hand, it can be seen that a small improvement in rollover threshold, such as from 0.38 to 0.44 g, through for example improvements to the suspension, has a very large beneficial effect on the incidence of overturning accidents.

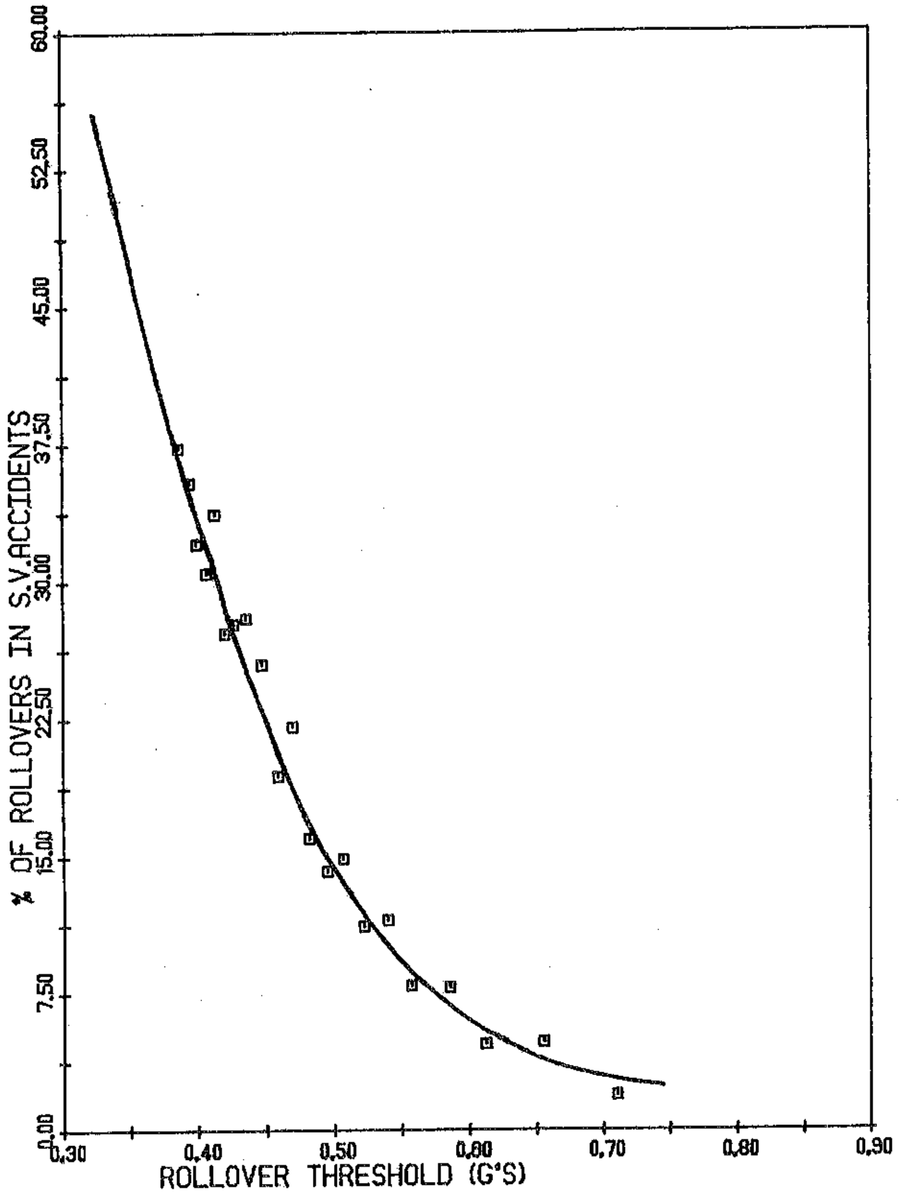

Figure 5.1
Relationship between Steady Cornering Rollover Threshold and Rollover Accident Statistics (9)

Vehicle designers can thus significantly improve rollover stability by paying particular attention to CG height (including height of the load), tyre track width and suspension properties.

5.2 Methods of Assessment

Quasi-statically the rollover stability of a vehicle or vehicle combination can be determined by several methods.

Driving the vehicle at gradually increasing speed in a circular path determines the rollover threshold (usually expressed in units of lateral acceleration) above which it would overturn.

Tilt testing imposes a loading condition which closely represents the constant radius cornering test. The component of vehicle weight acting parallel to the inclined tilt platform simulates the lateral acceleration experienced by the cornering vehicle (Figure 5.2).

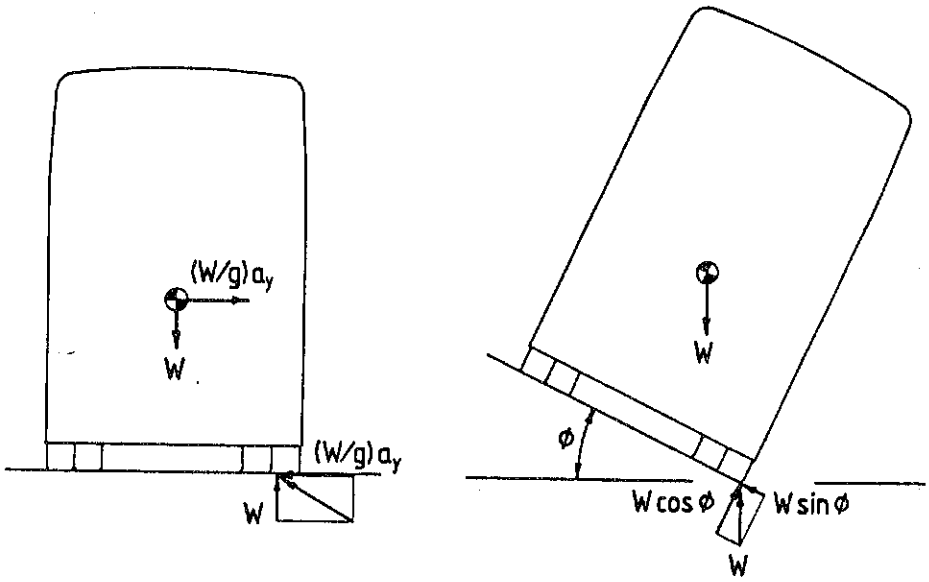

Figure 5.2, from (11)
Loading Conditions During Steady Cornering (left)
Compared with Tilt Test Loading (right)

Alternatively, either of these ful-scale tests may be simulated on a computer, provided that the appropriate vehicle parameters are first determined. Servo-hydraulic testing is an efficient method of measuring much of this data.

Dynamic techniques are necessary to study the effects on rollover stability of liquid loads, suspension damping and spring lash. This can be undertaken either by full-scale tests (such as a lane-change manoeuvre) or using appropriate computer software and vehicle data. It must be stressed that, unless manufacturers are knowledgeable and forthcoming about the properties of their products, measuring the necessary vehicle parameters can be time-consuming and expensive. Many of the parameters for a particular prime-mover or trailer are unlikely to have been measured before.

6. JACKKNIFE / TRAILER SWING

6.1 Description

Jackknife is the rapid rotation of the lead unit about the coupling with little change in the heading of the trailing unit. It happens to tractor-semitrailers when there is insufficient lateral force available at the drive axle. This is typically due to locking up the drive axle under braking, although excessive acceleration can also result in a jackknife. (It should be noted that an unladen truck pulling a laden dog-trailer can also be jackknifed. In addition, note that retarders and engine brakes apply braking solely to the drive axle(s) and thus should also be considered.)

Trailer swing is the slow rotation of a trailer about its coupling while the prime-mover remains predominantly unaffected. It is due to insufficient lateral force available at the trailer axle, usually when that axle is over-braked.

6.2 Method of Assessment

Braking compatibility calculations indicate which axles, if any, will lock up. This is covered in detail in the Braking Session of this seminar.

7. DISCUSSION

Recognising the significance of these various forms of instability on road safety, the DSIR has or is currently developing assessment capabilities in each of the areas mentioned above.

Linear models for trim stability and steady-state steering control analysis are operational for rigid vehicles and tractor-semitrailer combinations. This capability will be extended to cover the range of typical New Zealand configurations.

IRTENZ sponsored the purchase of a library of stability software from UMTRI. These are now functioning on a DSIR minicomputer. Simpler versions written to run on a PC should soon be available from UMTRI. AIDD is endeavouring to acquire these and a Fact Book containing typical vehicle and tyre data. These resources will enable AIDD staff to assess steady-state and transient handling and limit performance.

A tilt table is a very useful research tool, not only for studying steady-state rollover thresholds but also for measuring suspension and tyre properties and CG heights. AIDD lacks the financial resources to acquire a tilt table. On the other hand, AIDD has a good servo-hydraulic testing facility. Thus, our approach to assessing rollover stability will be to determine vehicle properties by direct measurement (applying forces and moments and measuring responses) and use these parameters as input data for computer simulation.

8. CONCLUSIONS

The safety record of heavy road vehicles in New Zealand needs further improvement. While drivers and road conditions are important contributory factors to road accidents, there is also plenty of scope for enhancement of vehicle safety performance. The importance of considering the various forms of instability during the design process is stressed. Trim stability, steering control, trailer fidelity, rollover, jackknife and trailer swing all need to be taken into account. Assessment methods exist for these various types of stability. Techniques available in New Zealand and capabilities under development have been outlined.

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