ARTSA Institute - Brake Calculator Manual

V1.1 19 January 2024

Warning and Disclaimer

The supply of any brake calculation is made subject to the following disclaimer:

The Brake Calculation produces computer-generated output from a mathematical model using available statistical and engineering models and provides a guide to performance that may assist professional Engineering Certification of vehicles. ARTSA-i gives no warranty and makes no representation as to the accuracy or reliability of the output data.

Modelled Data may not take into account vehicle conditions or your individual circumstances. You should obtain professional advice and judgment when considering the program outputs.

ARTSA-i give no warranty of any type, either express or implied, for the Brake Calculator tool (the Program), and any other material supplied with the Program; and the entire risk of loss, damage or unsatisfactory performance of the Program (no matter how arising, including as a result of negligence on behalf of the ARTSA-i) rests with the user (the User).

In no event will the ARTSA-i be liable for damages, including any general, special, incidental or consequential damages, arising out of the of the Program, any attempt to install the Program, the use of the Program, the inability to use the Program, the use of data embodied in, or obtained from, the Program or the use of any documentation or other material accompanying the Program.

The brake calculator project is funded by the National Heavy Vehicle Regulator's (NHVR) Heavy Vehicle Safety Initiative (HVSI), supported by the Australian Government.

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ARTSA Institute (ARTSA-i) was established to respond to the challenge of the rapidly changing heavy vehicle industry. It undertakes collaborative independent research and development work in the domain of heavy vehicle transport. The outcomes of its work are intended to inform the development of future policies of relevance to the heavy vehicel sector, and to provide useful information, training and services.

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1 Overview

The brake calculator allows the user to calculate the deceleration and stopping distance due to the service (foot) brake of the following types of heavy combination vehicles:

- ➢ Prime mover + Semitrailer. (3 or 4 axles on each vehicle)
- ➢ Rigid truck + two-axle (dog) trailer. (3 or 4 Axles on each vehicle)
- ➢ Prime mover + B-double trailer set. (3 or 4 axles on each vehicle)

Additionally, the following vehicles can be calculated:

- ➢ Semitrailer only (with the towing vehicle set to zero).
- ➢ Rigid truck only (with the trailer set to zero).
- ➢ Two-axle (dog) trailer only with rigid truck set to zero.
- ➢ Centre-axle trailer only (which is a Semitrailer with the axle group generally in the centre)

The calculator is applicable to vehicles that have compressed air braking systems.

The ARTSA-I Brake Calculator allows the user to determine changes to performance that will occur if the brake system on the vehicle is changed. Thereby road testing may be avoided in some instances.

The calculator can be accessed at: https://brakecalc.com.au. Users need to first register with the ARTSA (Email to exec@artsa.com.au). Registration will be subject to basic calculator training that is run periodically by ARTSA.

The purpose of the ARTSA-I brake calculator is to provide a tool that brake engineers can use to predict the braking performance of a combination vehicle to check compliance with technical standards. The relevant technical standards are:

- ADR 35/0* - Commercial vehicle brake systems.
- ADR 38/0* - Trailer brake systems.
- Vehicle Standards Bulletin Section G – National Heavy Vehicle Modification Code, brake certification.
- Performance Based Standards (PBS) – Directional Stability Under Braking.

* The last character is the revision level of the ADR rule. The current rules are 35/06 & 38/05.

The vehicle combination staring speed is specified by the user. Noting that the starting speed for tests specified in ADR 35 is different to that specified in ADR 38, the user can do two calculations using different starting speeds.

The brake calculator is not useful to calculate roadworthiness of vehicles because this depends upon the actual condition of the brakes on a vehicle, which can only be assumed for calculation purposes. Furthermore, the calculator assumes that the braking performance of the wheels on each end of an axle is identical, which may not be true in practice.

The ARTSA-I brake calculator calculates the combination vehicle braking at twenty brake control levels in the range 0 – 650 kPa. 650 kPa is also referred to as 1.0E. Therefore, the control increments for calculations is 32.5 kPa (0.05E). The brake control level is the air control pressure at the brake pedal in the motive vehicle. The axle control level at the axle group can be different because of air-valve characteristics in the axle control system. The user can specify the air system transfer characteristic between the brake control and the axle. This is described in Section 8.

Vehicle Type Selection

The first step to creating a new model is to select the vehicle type. The first screen of the brake calculator is:

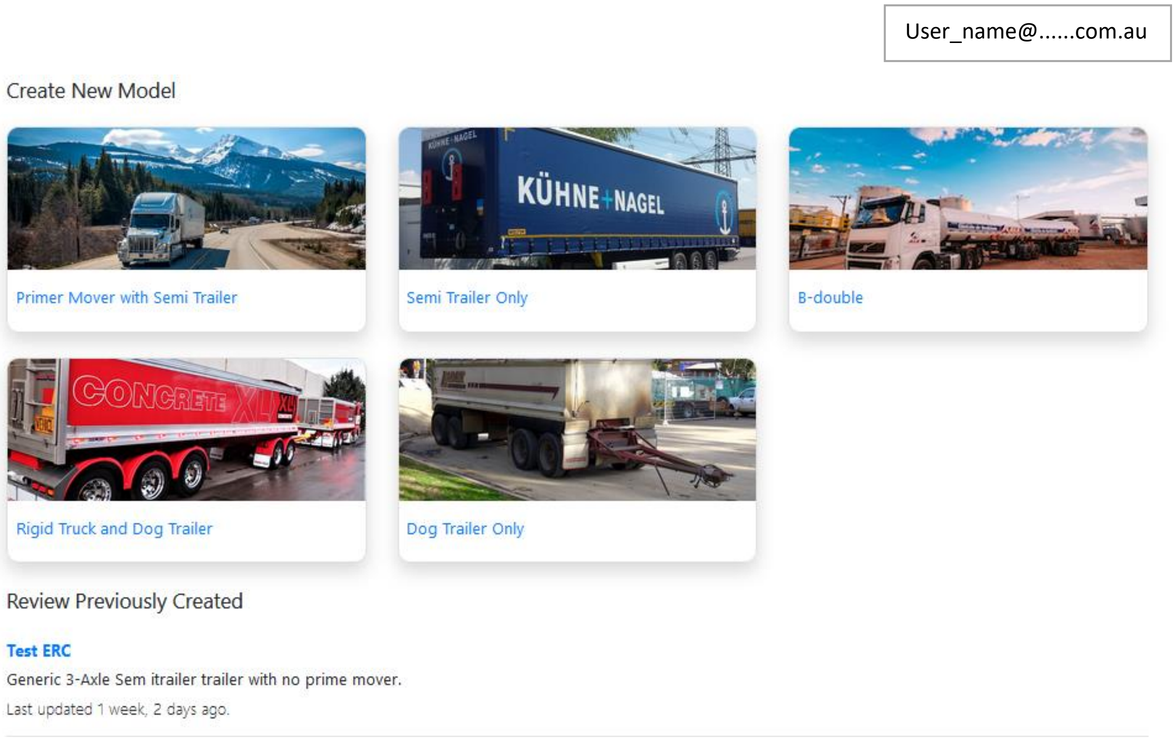


Figure 1   Vehicle Types

Registered users can store models and recall them. The stored models for the user will be listed on this first page and can be recalled. In Figure 1, Test ERC is a model that was created and stored after selecting the Semi-Trailer only.

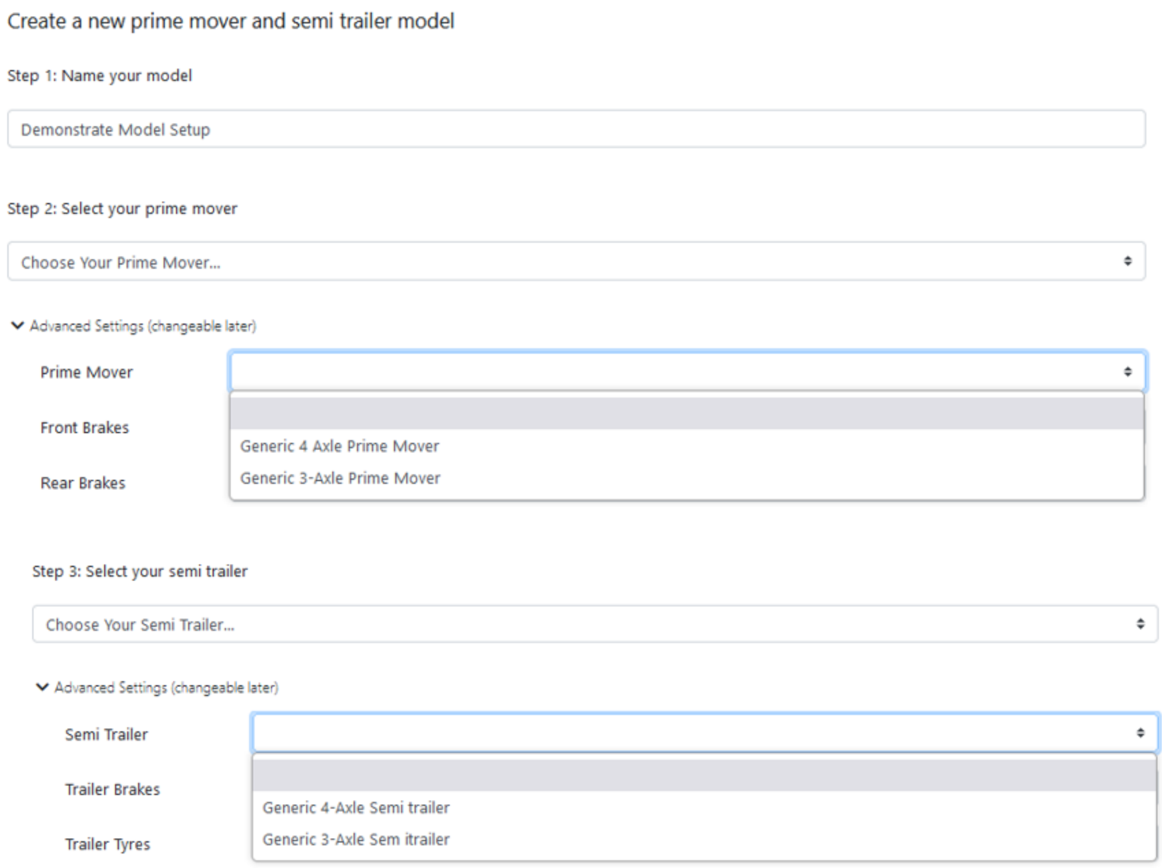


Figure 2 Example of creation of a prime mover and semitrailer model.

Once created, the model will be saved by the brake calculator program in a user folder. It will be kept according to ARTSA's file retention policy. It will not be made available to other users.

The user can select 'generic' vehicle parts that have pre-set brake parameters. The settings can be changed after selection. The generic models are provided to allow fast set-up.

The user can specify the lengths, weights, air control ratios and brake types on all the parts of the selected combination vehicle. Following sections in the manual will describe how this is done. Once the model is created it can be Renamed or Deleted, once it is reselected.

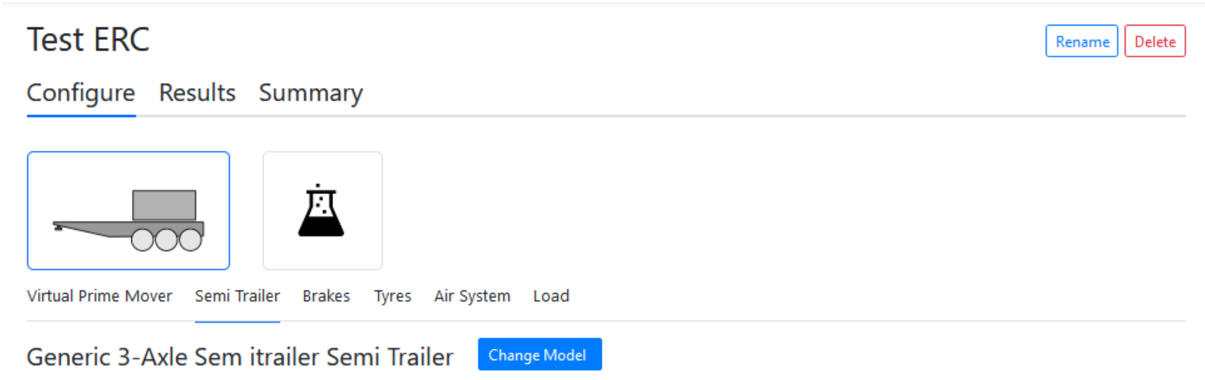


Figure 3 Illustration of model Rename and Delete functions.

In this manual:

- Vehicle part means either the motive vehicle or one of the trailers.
- Vehicle combination means the combination of all the vehicle parts.
- Truck means the motive vehicle.

Each vehicle part has axle groups. For all types excluding a semi-trailer, the vehicle part has two axle groups, front and rear. The Semi-Trailer only type has the Prime Mover set to zero weight, zero brake force and 1:1 air system characteristic.

The Outputs of the Calculator are:

1. Braking Utilization of each vehicle part and Deceleration of the combination vehicle as a function of the braking control level. The brake control level is at the foot pedal of the service brake.

2. Utilization of each axle group in the combination vehicle as a function of brake control level.

3. The weights on each axle group of the combination vehicle as a function of brake control level.

4. The stopping distance as a function of the brake control level, on the specified slope.

5. The parking brake performance on a specified slope.

The outputs are displayed graphically. Examples are given in Figures 4, 5 & 6 below.

The brake control level is the brake control air pressure at the foot pedal of the motive vehicle. 1 per unit brake control level is 650kPa.

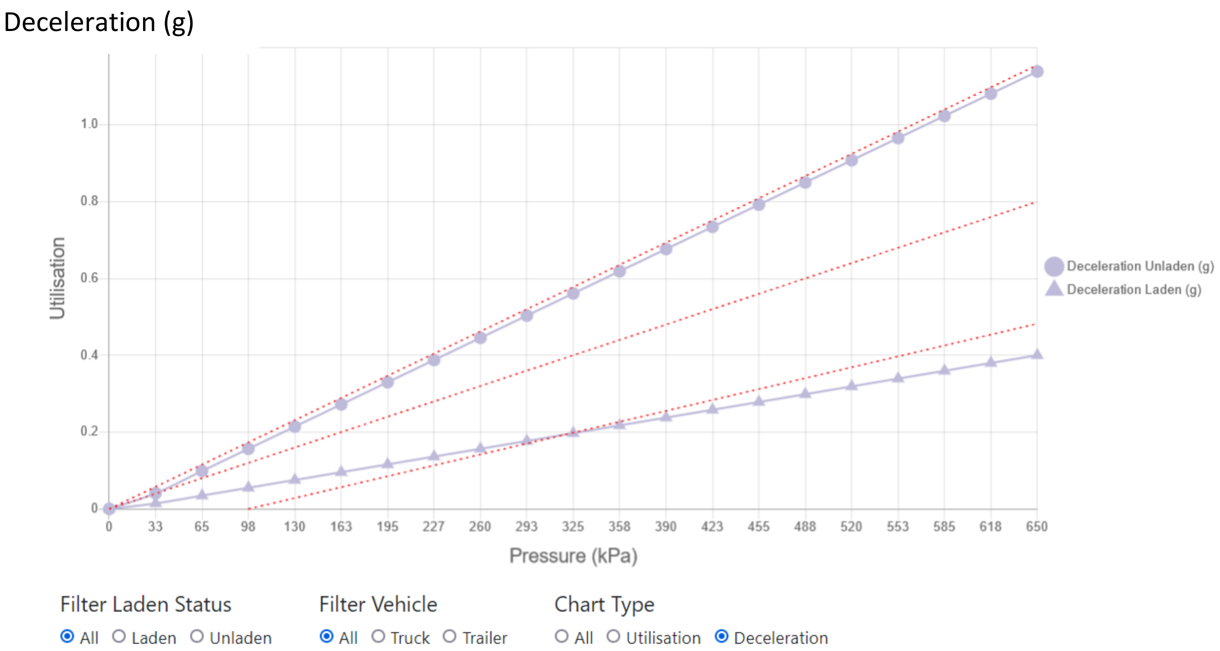


Figure 4 Utilization V control pressure performance graph for a truck and trailer.

Dotted red lines are:

Bottom - ADR 35/38 minimum ERC limit
Mid - ADR 35/38 laden maximum ERC limit.
Top - ADR 35/38 unladen maximum ERC limit.
(ADRs35 does not regulate axle group utilization. ADR 38 does regulate dog-trailer axle utilization)

The pressure axis is the brake control level. The deceleration of both truck and trailer must be the same

The performance of the unladen vehicle (assuming tare weights only) and the laden vehicle (tare and load wights included) are calculated simultaneously.

The graph in Figure 5 shows the axle-level performance. The axle-group friction Utilization is defined as follows:

Axle Group Utilization = Axle Group Braking Force / Axle Group Mass. …(1)

For the (combination vehicle), Deceleration of a vehicle (m/s^2) = Utilization x 9.8061 m/s^2.

Axles within the same group can be individually specified in the Advanced Axle Specification Module.

The calculator also calculates the Utilization of individual axles which is defined as follows:

Axle Utilization = Axle Braking Force / Axle Mass. …(2)

The Axle Mass is assumed to be the same for each axle in the group.

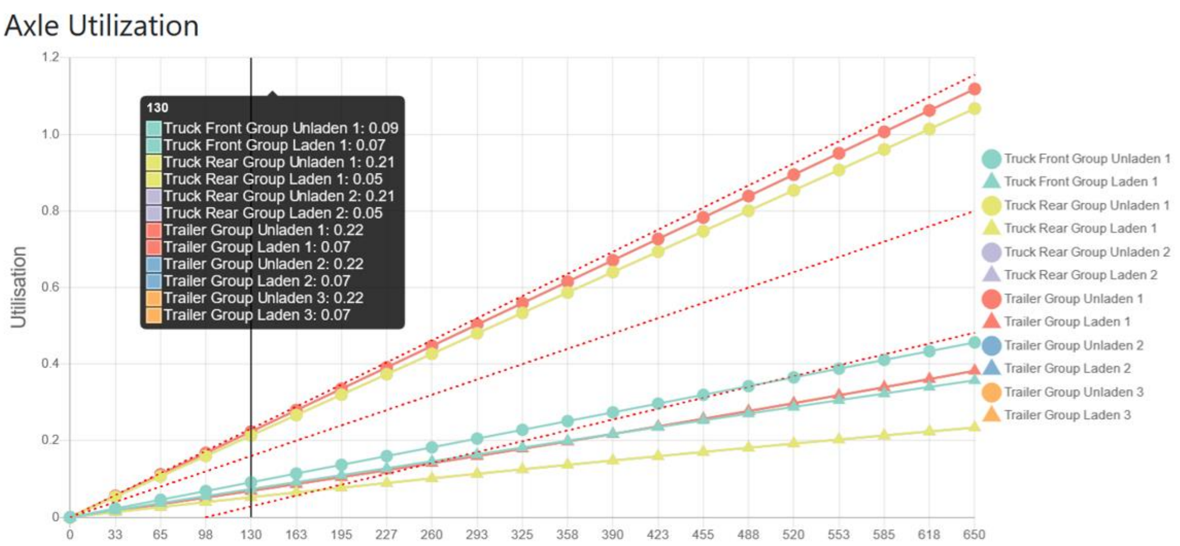


Figure 5 Axle utilization V control pressure performance graph.

Axle utilization = Axle brake force/ Axle weight force

Dotted red lines are:

Bottom - ADR 35/38 minimum ERC limit
Mid - ADR 35/38 laden maximum ERC limit.
Top - ADR 35/38 unladen maximum ERC limit.
(ADRs35 does not regulate axle group utilization. ADR 38 does regulate dog-trailer axle utilization)

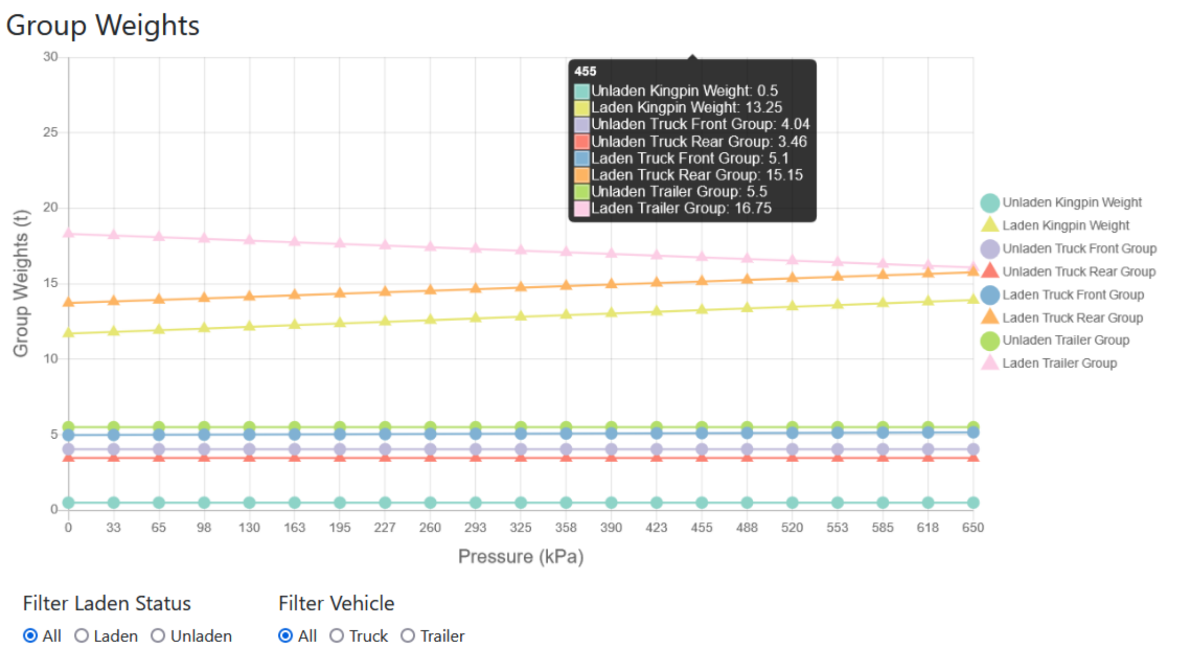


Figure 6 Weight on the identified axle group V control pressure graph.

The mass on each axle of the vehicle, and on the kingpin(s) during braking is calculated and can be displayed.

The stopping distance for each brake control level is calculated using the calculated deceleration for each control level. The calculation takes account of time delays specified by the user that occur when the service brake is first applied. Further details are given in Section 13. It should be noted that the calculator operates in the pressure domain and not the time domain. The stopping distance calculation assumes that the brake control level is kept constant during the entire stop. This calculation uses a single pressure build-up time delay that is calculated as an average of the individual vehicle 'Pressure Time Delay until 420kPa(s)' – also see Figure 12.

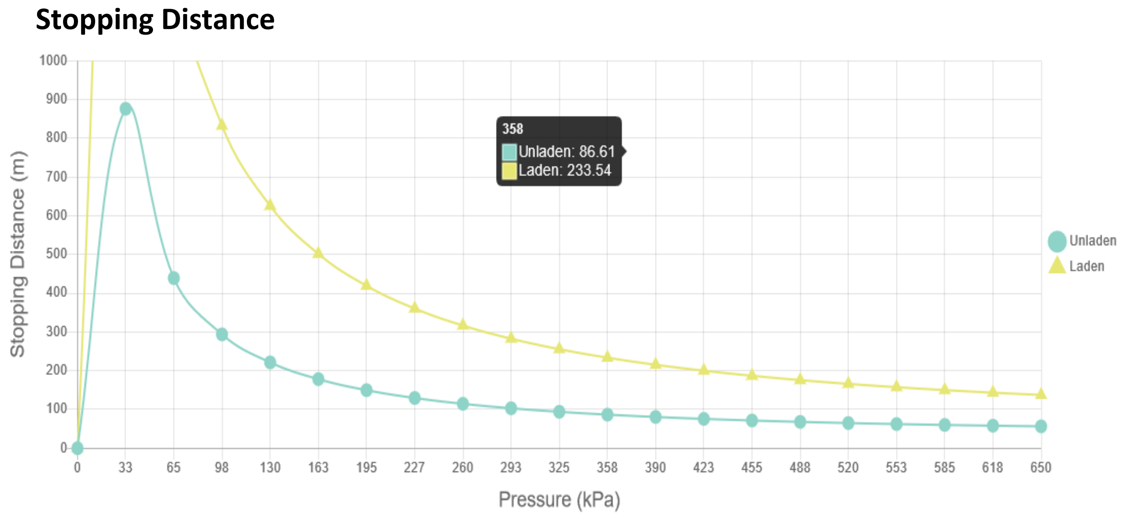


Figure 7 Stopping distance V control pressure performance graph.

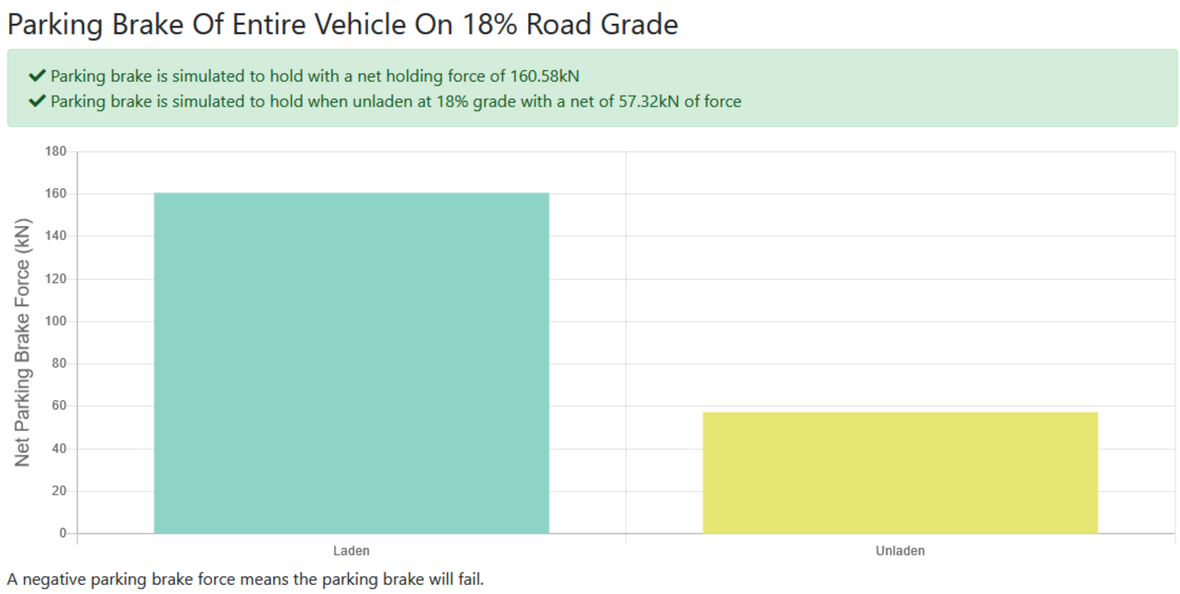


Figure 8 The parking brake force in laden and unladen conditions.

The user specifies which axle groups have parking brakes. It is assumed that all axles in that group have parking brake actuators. The total parking brake force on the combination vehicle is calculated. The total down-hill force due to gravity on an 18% grade is calculated. The output graph above shows the net parking brake force that is available (Parking brake force – Gravity Force). If the graph is positive, then the combination vehicle cannot be held.

The parking brake force is limited by both tyre slip and brake capacity. For this reason, the unladen parking brake force can be less than the laden parking brake force.

The Weights (Masses) Used By The Calculator Are:

- User specified vehicle part tare weights.
- User specified vehicle part axle group weights.
- User specified load weights on each vehicle part.

Calculations are done for both the laden combination vehicle and for the unladen combination vehicle. In the latter case, the calculator puts all loads to zero. All the results described above are available for both the laden and unladen combination vehicle and its parts.

The mass on each axle group is calculated taking account of the vehicle deceleration. Weight transfers from rear axle groups onto front axle groups because the centre of mass height on each vehicle part is above the axle height. Using physical principles, weight will transfer forward during deceleration.

The user can select 'generic' load masses for a given type of combination vehicle, as described in Section 6. This facility is provided so the user can easily apply the same load to multiple vehicles of the same type to compare performance.

The Road Conditions That Can Be Selected Are:

The Road Friction is the road-to-tyre friction coefficient, which is assumed to be the same for all tyres on the combination vehicle.

Road Friction = Max. Braking Force on tyre at lock-up / Weight Force on tyre at lock-up

… (3)

The calculator assumes that the braking performance and load carried by the wheels on each end of an axle are identical. The brake torque that the user specifies is the total axle brake torque.

The calculator assumes that the Road Friction is the same for tyres that are laden and unladen. However, the user can recalculate using another Road Friction for the unladen combination vehicle if desired.

The Calculator contains a tyre lock-up model. If a tyre has locked up, the braking force that it produces does not vary with increased pressure and it is discounted by a user-specified Factor.

Note that throughout this manual:

Weight force (Newtons) = Mass (kilograms) x 9.8061 …(4)

Road Grade (slope) can be specified:

Zero Road Grade is for a uniform flat road.

A positive value is for a uniform uphill road. The specified value is the percentage slope.

A negative value is for a uniform downhill road. The specified value is the percentage slope.

The Initial speed at the start of braking is specified in km/h. The brake force calculations are independent of speed except for the drum brake discount that is described in Section 11.

The driver delay in applying brakes is a time in seconds that the vehicle travels unbraked before the brakes are applied. It is not a time delay on each vehicle part for the brakes to apply because of pneumatic delays. Pneumatic delays are specified elsewhere.

Novel Features in the ARTSA-I Brake Calculator:

The ARTSA-I brake calculator differs from many other calculators because:

1. It contains a tyre lock-up model.
2. It calculates the masses on each axle group during braking and uses this information to predict tyre lock-up.
3. It contains a drum brake discount that predicts heating up of the drum brake on the laden vehicle and reduces the torque available from the drum brake as a function of deceleration. This discount does not apply to a disc brake. If the user does not want the drum brake discount, then specify the desired brake torque level with the brake specified as 'disc brake'.
4. The air system characterises can be specified between the brake control point (at the foot valve of the motive vehicle) and each brake group.
5. The user can specify a trailer brake valve characteristic for the through air-path.

Consequently, the ARTSA-I brake calculator may give different results to other calculators that do not have these features.

2 Capabilities

The ARTSA-I Brake Calculator will calculate for laden or unladen vehicles on a flat or sloping road.

The user can specify:

- Starting speed (Figure 10).
- Available road friction (μ, Figure 10).
- Road grade (Figure 10).
- Tyre lock-up factor (Figure 10).
- Driver Delay in applying brakes (Figure 10).
- Vehicle dimensions (Figure 12)
- Vehicle loads (Figure 12).

➢ Brake type, performance and set-up for each axle group (Figures 13 & 14).
➢ Air control system ratios, delays and thresholds (Figure 15 & 16).

. The calculator assumes that the brake performance on each side of an axle is the same.

3 Situation Settings

After selecting the vehicle combination to be calculated, the user is required to :

- specify the dimensions, loads and equipment on each vehicle part;
- specify the road settings that apply.

These specifications occur in the Configure module:

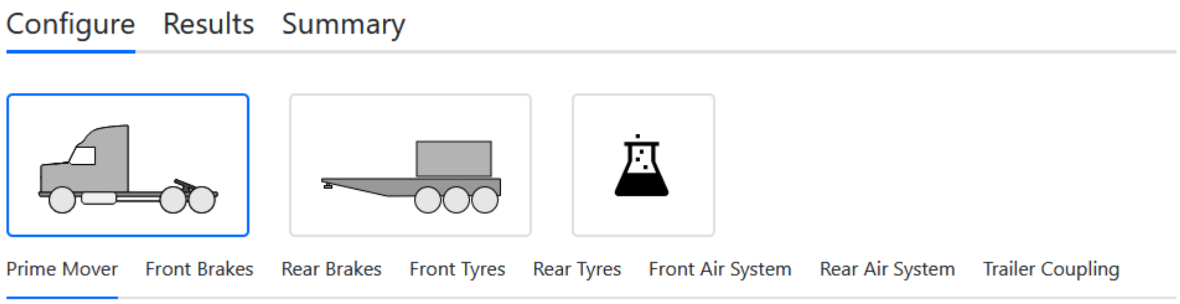


Figure 9 Select either a vehicle part or road settings

4 Road Settings

They can be reached via the Settings icon:

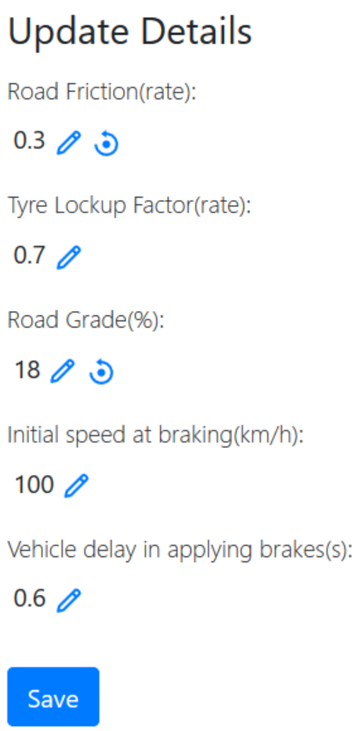


Figure 10 Road setting factors page

The pen symbol on any user screen (e.g. Figure 10) allows the user to change the numerical factor for the parameter. The arrow symbol indicates that the value has been changed. By selecting the arrow symbol, the original (default) value is reapplied.

The road-tyre friction value is the ratio of brake-force/weight-force for which wheel lock-up occurs. The user can suppress wheel lock-up in the calculations by setting the Road Friction to an unrealistically high value (e.g. 5).

The tyre lock-up factor is the proportion of the peak brake force that a locked wheel provides for all brake control levels above that which causes wheel lock-up. For a locked wheel, the braking force provided that the wheel is:

Peak retardation force prior to lock-up x Tyre Lockup Factor. …(5)

Vehicle delay in applying the brakes is a constant time delay experienced by all axle groups due to slow driver response. It is in addition to air system time delays that occur on each vehicle, which can be specified when the brakes are specified

The road grade is the slope of the roadway (assumed constant slope) that the vehicle experiences. Downhill braking has positive values of slope and uphill braking has negative values of slope. The angle θ of the road from horizontal can be calculated as follows:

Slope = 100 x Tan(θ) **θ = tangent of the slope angle** …(6)

To assist the user, the following generic road settings are available:

Name:	Dry Road Conditions
Limiting road friction:	0.75
Lock up factor as a unitless value between 0 and 1:	0.7
Gradient of the road:	0.0
Initial speed:	100.0
Driver application delay:	0.0

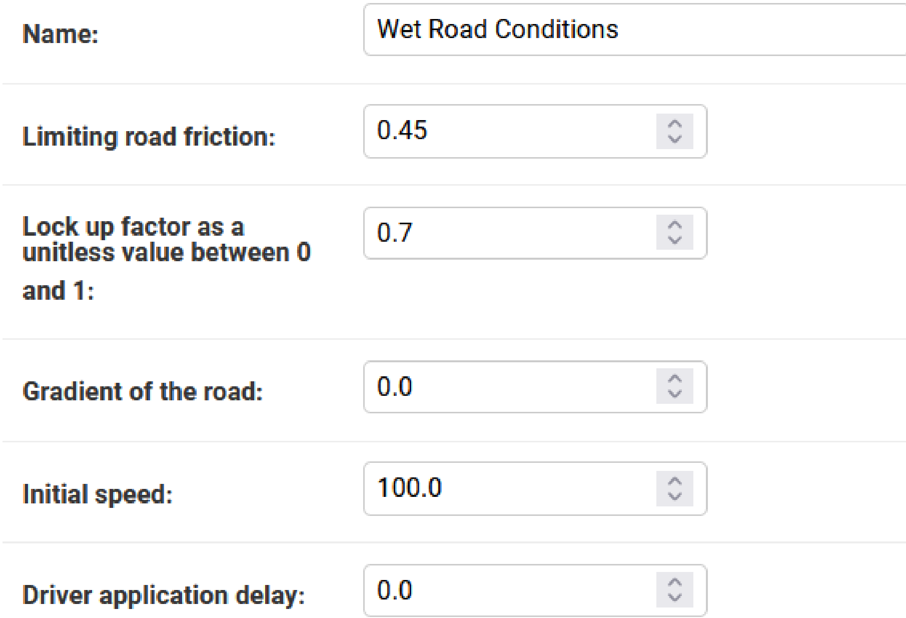


Figure 11 Generic road friction settings.

Notes:

The Centre of Mass height is measured from the axle height and not the ground. The reason for this is that weight at axle height does not transfer to the towing vehicle.

The reference length is measured from the front axle of a truck and a dog trailer. The reference length is measured from the king pin of a semi-trailer. A centre-axle (pig) trailer is modelled as a semi-trailer with the front coupling at the ‘kingpin’ location.

For a trailer with two axle groups (‘Dog trailer’), the reference length is measured from the centre of the first axle group.

5 Vehicle Weights and Dimensions

The vehicle weights and dimensions are specified in the Configure module:

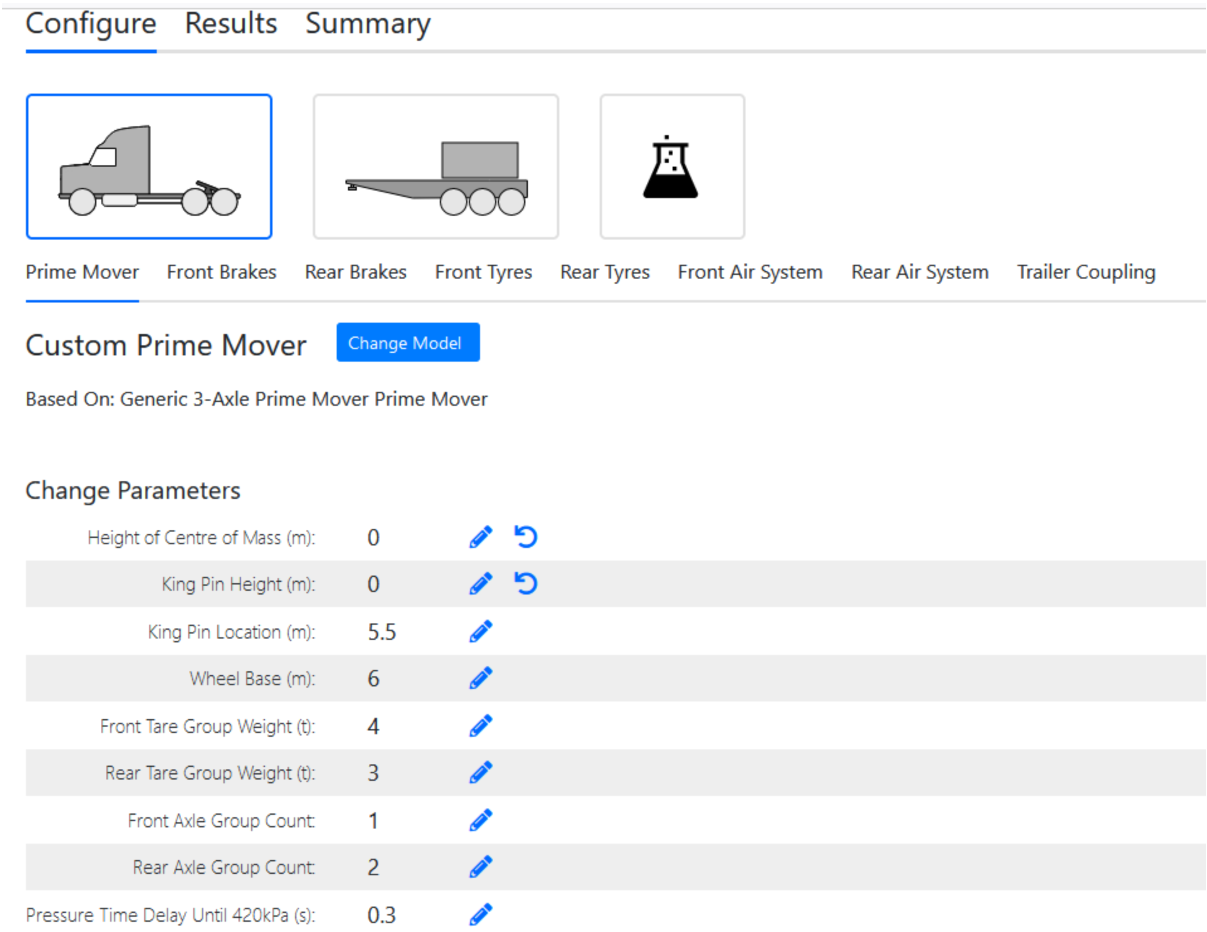


Figure 12 The first page allows the user to specify weights and dimensions.

The Calculator is set-up with typical or generic values for each parameter. This allows the user to quickly start calculating. Follow-on calculations can be easily done without having to respecify most parameters. In Figure 12 the heights of the Centre of Mass and King Pin Height were set to 0 to suppress load shifts on the Prime Mover vehicle.

The user can specify 1 or 2 axles in the Prime Mover steer axle group.

The User can specify 1, 2, 3 or 4 axles in the Prime Mover rear axle group.

The User can specify 1, 2, 3 or 4 axles on a Semi Trailer.

The User can specify 1 or 2 axles in the front axle group on a Dog Trailer (which is a trailer with two axle groups).

The User can specify 1, 2, 3 or 4 axles in the rear group of a Dog Trailer.

A Centre-Axle Trailer (Pig Trailer) is modelled as a semi-trailer with the load positioned towards the centre of the axle group.

Longitudinal dimensions are specified from the following Reference Lines:

- The front axle on a truck.
- The kingpin on a semi-trailer.
- The front axle on a trailer when the trailer has two axle groups.

The wheelbase of a vehicle is measured from the Reference Line to the centre line of the rear axle group.

Height dimensions are specified from the centre of the axle and not the ground.

6 Brake Torques

An example of brake selection for the front brakes on a prime mover is shown below. The specification in Figure 13 is for a brake torque at 1E control level of 10kNm.

The user can also select an approved brake type. Twenty brake types are listed. These are based upon approved Australian brake sub-assemblies, called SARNs. A range of approveed brake types are available. The procedure to select an approved brake type is shown in Figure 14. There are four Generic brake types than can be selected: 16” x 5” drum, 16.5” x 7” drum, 19.5” disc and 22.5” disc.

Different brakes can be selected for different axles in the same group. This can be done in Advanced Mode, as shown in Figure 14.

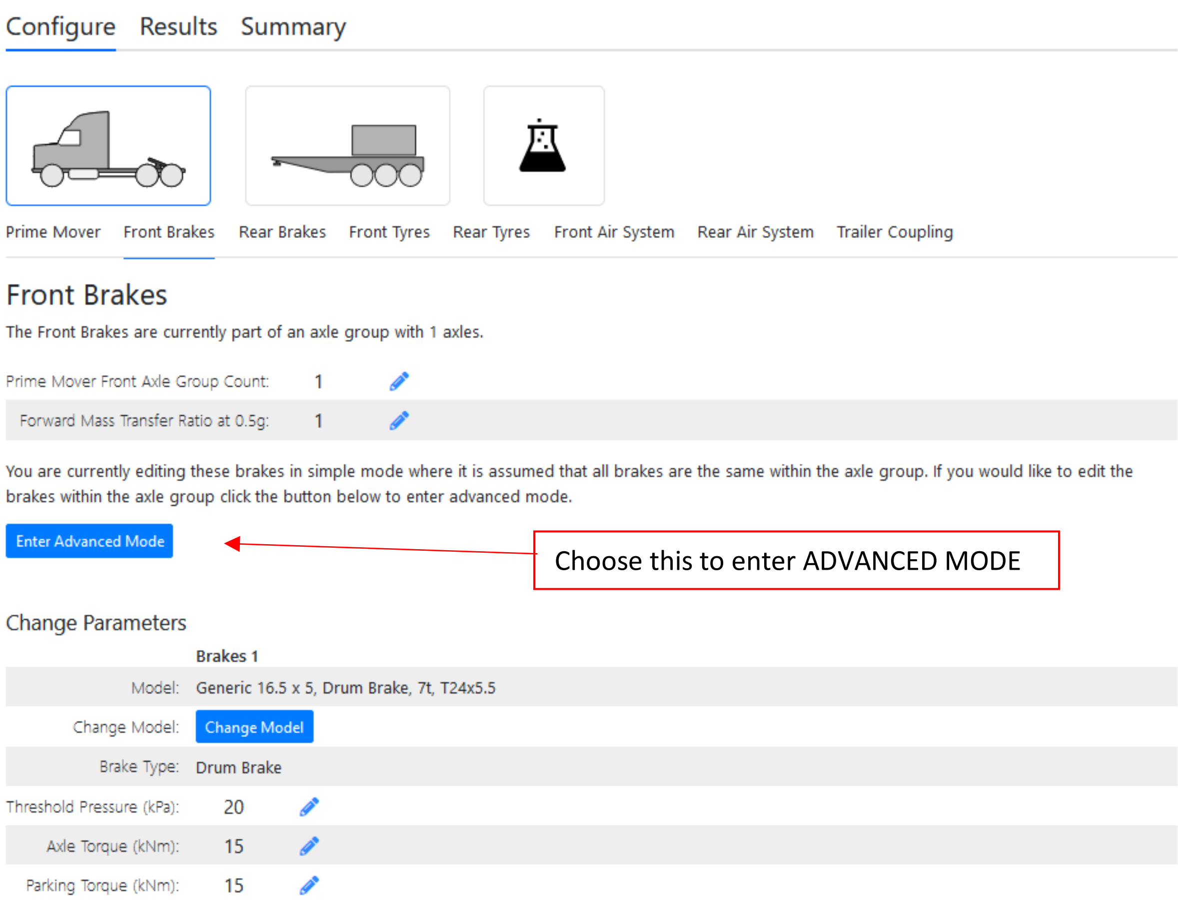
The Threshold pressure should be specified. This is the brake air pressure needed to cause the brake to engage. This Threshold Pressure subtracts from the control level that the air control system delivers to the brake.

Foundation brakes can be selected from a library of foundation brake makes and models that are approved in the Australian vehicle certification system – ROVER and its predecessor RVCS. These approvals are described as CTA – Component Type Approval or CRN – Component Registration Number. Each entry has the approval number in the title as well as the manufacturer’s description for the brake.

The brake selection fills in the:

- Threshold air pressure – which is the minimum air pressure required to cause the brake to generate torque.
- Brake torque at 1E brake control level.
- Parking brake torque.

All these values can be over-ridden.



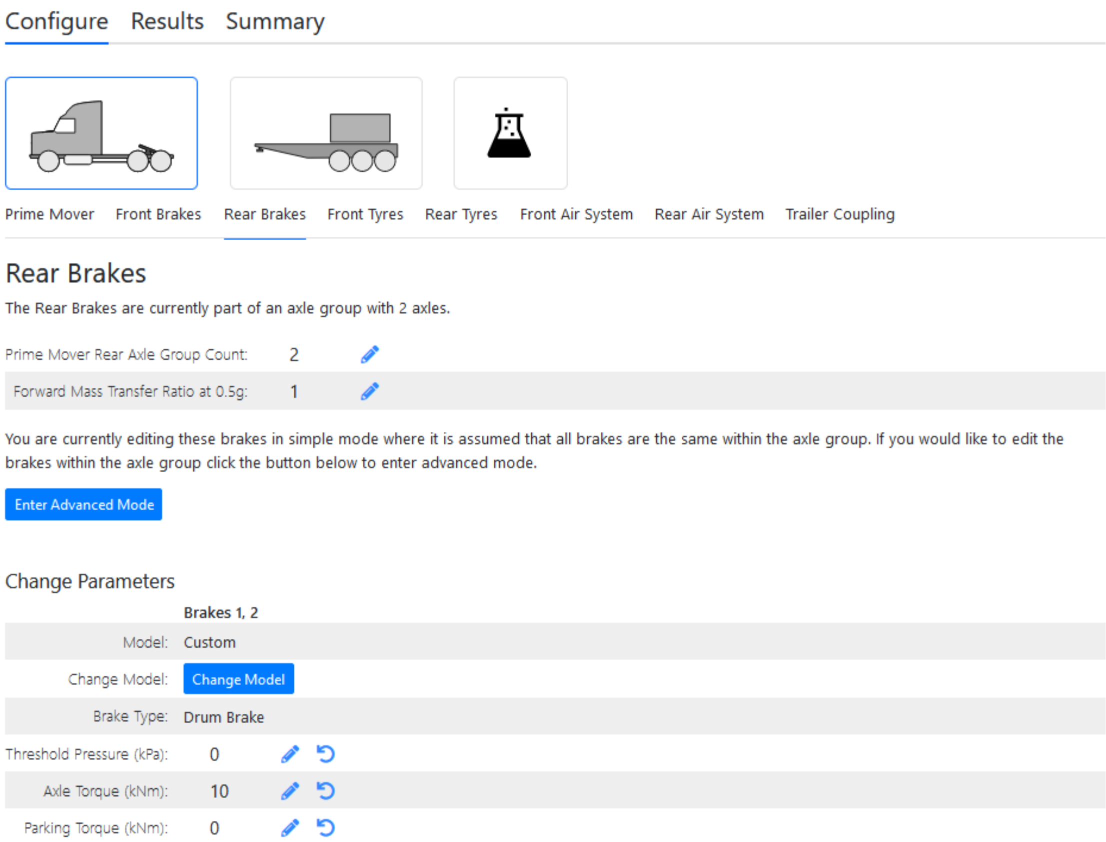


Figure 13 The front (top) and rear (bottom) axle brake selection page – SIMPLE MODE

In ‘SIMPLE MODE’ the one brake selection is applied to all axles in the group. Additionally, it is assumed that the weight on each axle group is shared equally between axles in that group. That is, there is no suspension brake reactivity in SIMPLE MODE.

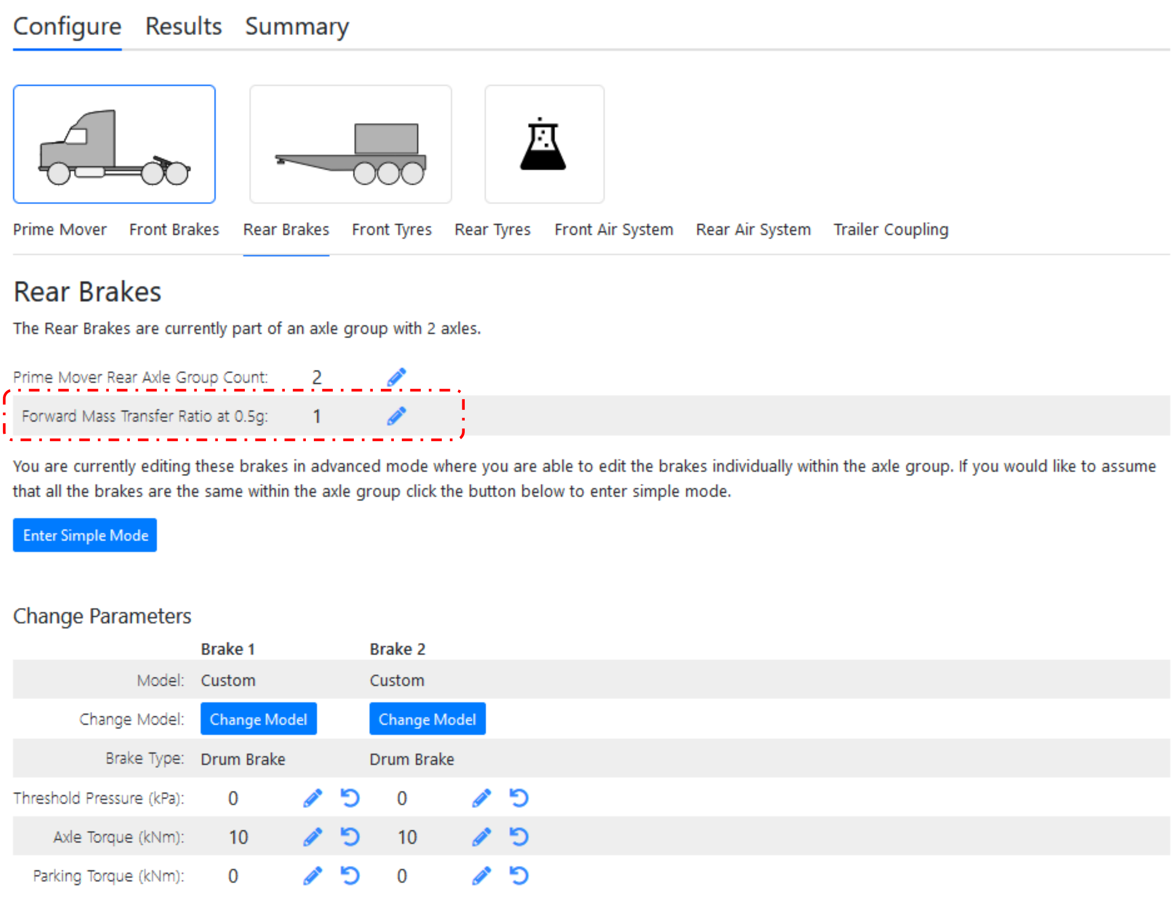


Figure 14   Brake Specification in ADVANCED MODE

In ‘ADVANCED MODE’ individual axles in the group can be specified. In Figure 14 there is a separate column for each axle. The brake specification can be different on each axle.

It should be noted that the program assumes that the brake torque is a linear function of the control air pressure that reaches the brake. The brake testing that brake suppliers are required to do to obtain ADR 38/0* component type approval, requires the brake torque to be determined by tests at five different control pressure levels in the range 0.2E – 1.0E. The vehicle is to be laden and the weight distribution such that the propensity for wheel lock-up minimised. Test results are not reported if tyre lock-up occurs during the tests. A single brake torque value is stated on the CTA reports available in the Australian ROVER system. This corresponds to a ‘straight-line’ value through the available test results, that is extrapolated to 1.0E control pressure. Therefore, the brake torque values reported may be different to those obtained during testing.

The program does not use the brake actuator size Ac or the slack adjuster length Sl in any calculations. The User can explore the effect of changing the actuator area or slack adjuster length by altering the brake torque value at 1.0E using the following nominal relationships:

Altered Brake Torque = Reference Brake Torque …(7)

x (Altered Actuator Area/ Reference Actuator Area)

x (Altered Adjuster Length/Reference Adjuster Length)

For example, assuming the Reference brake is SAF HOLLAND RZ-20, the report on the ROVER portal is that:

> Reference Torque = 3.107 kNm. Reference Actuator Area = 202 cm^2. Reference Adjuster length = 152mm.

If the brake was altered as follows:

> Alternative actuator = 137 cm^2. Altered adjuster length = 127mm.
>
> Altered torque = 3.107 kNm x (137/202) x (152/127) = 2.522 kNm.

The use of the Forward Mass Transfer Ratio is explained in Section11.

7 Drum Brake Discount

Drum brake performance drops off when the brakes get hot. This is due to expansion of the brake drum and the reduction of friction level of the friction material. Consequently, the average deceleration that occurs when a vehicle is stopped is lower as the starting speed is increased. As a guide, a fully laden vehicle that can achieve a 5 m/s^2 average deceleration from 60 km/h will achieve about 4.5 m/s^2 from 100 km/h. This reduction occurs because the drum brakes heat up during the stop and this changes the drum diameter and the brake lining friction level. Based upon this observation, a brake drum discount of about 10% for a fully laden vehicle starting from 100km/h is applicable.

The discount is applied because the brake torque values that are stated in the SARNs are determined by tests from 60 km/h and the energy that the drum brakes must absorb starting from 100km/h is 278% greater than required from 60 km/h. If the vehicle is fully loaded, the energy to be absorbed is proportionately greater. Therefore, the drum brake discount takes account of both initial speed and load.

The program discounts the drum brake torque value using the following model:

Drum brake torque = Reference drum brake torque x (1 – F1) ...(8)

F1 = (initial speed-60)/400.

For example, if the initial speed = 100 km/h, the drum brake torque will be:

90% x Reference drum brake torque.

No discount is applied to disc brakes. Changing starting speed will not alter the deceleration level for a vehicle with disc brakes, but may for drum brakes. The drum brake discount can be avoided for a drum brake by selecting a disc brake from the menu and then over-riding the selected brake torque with the desired drum-brake torque for that axle.

Whilst a more complicated drum brake discount factor calculation could be contemplated based upon the energy to the absorbed by the brake, there is no reference work on which to base such a complex discount formula. What is known is that the average deceleration performance standard for heavy trucks (ADR 35/0*) is 3.78 m/s^2 from and initial speed of 100km/h; and for trailers the performance standard is 4.50 m/s^2 from an initial speed of 60 km/h. This suggests an 84% discount based upon starting speed only. Real work brake test experience verifies that the higher the starting speed, the lower is the average deceleration that is achieved. This is the basis of the decision to include a discount factor in the brake calculator. If the user does not want to have a discount factor, then the brake type can be respecified as disc without any other effect on the calculations.

8 Air System Specification

The air system transfer characteristics between the brake control in the motive vehicle and each selected axle group can be specified at five pressure levels. A piece-wise linear air system characteristic is created using the five specified transfer values. The air pressure that the axle group experiences for each of the 20 control pressure levels (P), is the control level multiplied by the transfer characteristic level.

For example, in Figure 15, the calculated air pressure that the brake experiences at 1.0E control level (650kPa) is 0.9 x 650kPa = 585kPa (0.9E). At 40% control pressure level (260kPa) the brake experiences a control level = 260 kPa x 0.95 = 247kPa (0.38E).

The brake torque to be used in calculations at each control pressure level is:

(**Brake torque at 1E air pressure) x** …(9)

(calculated Axle control air pressure – Axle threshold air pressure) / 650kPa.

For trailers an additional transfer characteristic can be applied. This is a series valve characteristic that provides a boost characteristic that is also applied to the trailer axle group. That is, two transfer characteristics are applied to each axle group.

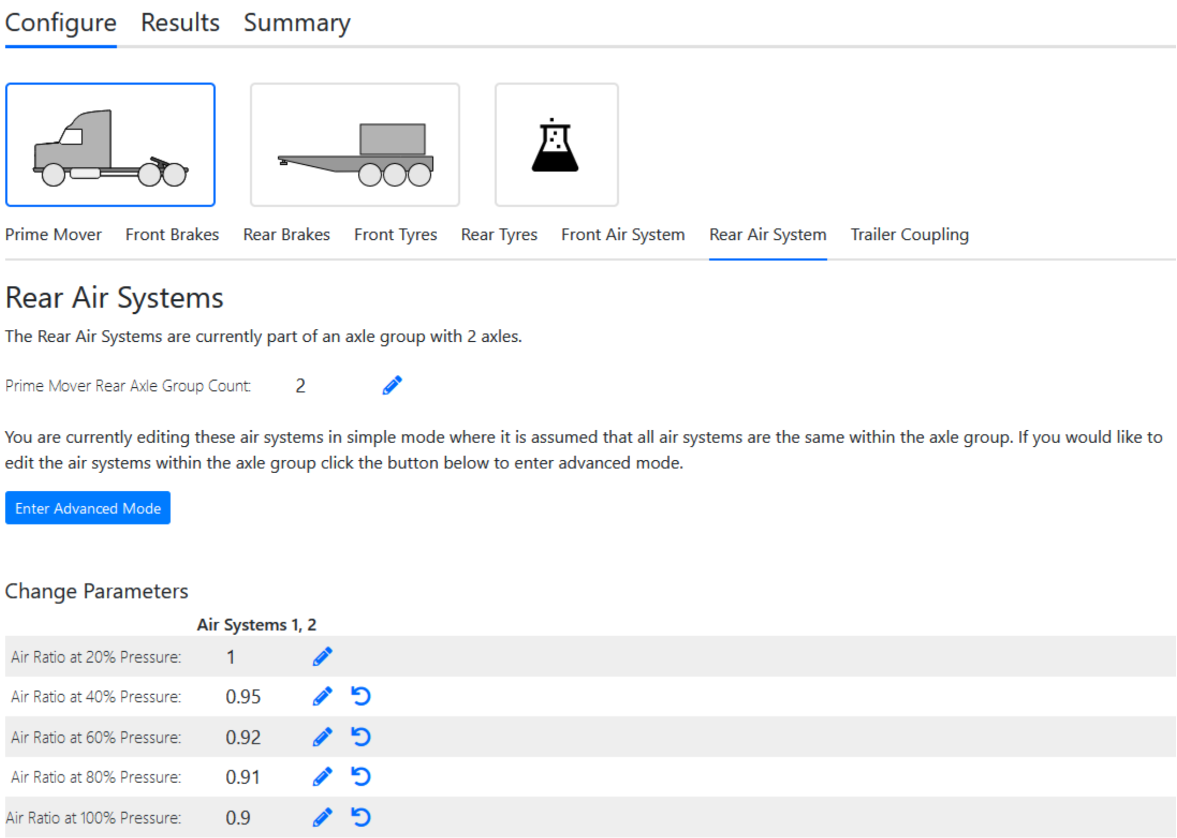


Figure 15 The air transfer characteristic is specified as a piece-wise linear characteristic at five pressure levels.

The ratios apply at the specified axle group. They relate to the control level at the control point in the cabin. For example, based upon the specification in Figure 15, the air pressure at the axle group when the control is 60% is as follows:

E.g: Axle pressure (60%) = 0.6E x 650kPa x 0.92 = 358.8 kPa.

Note that the control air transfer characteristic to the trailer coupling on the prime mover can also be specified. Hence, the trailer can receive a different control air pressure to that of any axle group on the prime mover. This feature is available for each vehicle. Figure 16 illustrates the specification of a trailer ‘through path’ transfer characteristic. The specified transfer characteristic is shown on the graph. If for example, if the control air pressure at the front trailer coupling was 0.6E, the program will calculate assuming the control air pressure to the following trailer is 0.6E x 0.8 = 0.48E. The calculator with cascade the through-path transfer characteristic so that trailer 2 will experience the transfer characteristics of trailer 1 multiplied by the transfer characteristic of the prime mover.

Figure 16 Example of the air transfer characteristic for the through path on a trailer.

9 Basis of the Calculations

Calculations are made for each of twenty control levels:

650 kPa is defined as 1E in the brake design rules. The calculation interval is 0.05E.

In the following description, axle pressure is expressed in the 'E-scale'. (32.5, 65, …. , 650kPa).

The calculation of deceleration is based on Newton's Second Law:

Vehicle Deceleration = Total Brake Force on the vehicle/Total Vehicle Mass …(10)

Drag forces due aerodynamic and tyre losses are not considered.

The air pressure for each control level at each axle group is calculated taking account of the threshold pressure and valve characteristics at each trailer coupling.

The retardation force generated by the brakes on each axle is calculated as follows:

Force = Axle Pressure x Torque at 1E / Tyre radius **…**(11)

The potential axle retardation force may not be transferred to the pavement. The calculator includes a wheel lock-up model. If the wheel has locked up, the Force generated is reduced according to the procedure described in Section 11.

The mass distribution formulae that is applied to the axle groups on each vehicle in the combination is shown in Figure 17. The mass is distributed between axles as described in Section 11.

These formulae are applied to each vehicle in the combination, starting from the rear trailer. Thereby the weight on each axle group is calculated as a function of the estimated deceleration.

Red arrows in Figure 17 represent the retardation forces that the brakes cause at the axles. The retardation forces depend upon brake capability, control air pressure level and whether the tyres on the axle have locked. The following sections describe how the retardation forces are calculated and how the deceleration of the (combination) vehicle is calculated.

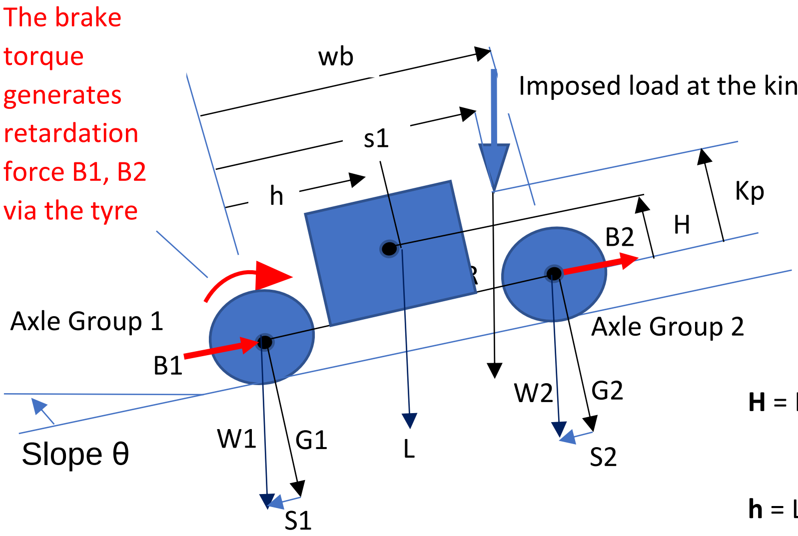
The road slope can be specified. The load transfer from a towed vehicle to the towing vehicle is not altered. The axle friction utilization is calculated using the weight on the axle and not the normal component of weight.

The friction utilisation is calculated from the calculated axle retardation force and the calculated weight force on the axle.

Because estimation of wheel lock-up depends upon mass transfer that in turn depends upon deceleration level, the calculation process is iterative, as described in Section 12.

10 Mass Distribution Between Axle Groups

The formulae used to allocate mass between axle groups during braking and on a slope are shown in Figure 17.



H = Height of Load centre of mass above axle level (m).

h = Length of Load centre of mass from reference line (m).

C = Centre of tare mass height (m).

c = Centre of tare mass length tare (m).

Kp =Height of the kingpin.

skp = position of the kingpin.

wb = wheelbase (m).

R = Tyre radius (m).

Slope angle θ. Slope percentage = 100 x Tan θ

Tare mass is not illustrated. Tare and load mass are split between on the axles independently.

The curved arrows signify that the source of the brakes forces B1, B2, Bi are generated by a brake torque that is applied via the tyre radius R.

L= added load mass (tonnes)

T = vehicle tare mass (tonnes)

Bi = brake force at tyre i (kN)

Gi = normal force at tyre I (kN)

Ni = Friction utilization of axle group i

Wkp = imposed load on fifth-wheel coupling (tonnes)

Wi = mass force on axle i (tonnes)

Si = Slope force at tyre I (kN) when slope θ is not zero.

Total Vehicle Mass = **T + L + Wkp = M**

Ni = **Bi** / **Gi**

Figure 17 Axle weight distribution

The formulae that are used to distribute mass between axle groups (including the king-pin on a semi-trailer as if it were an axle group) are shown below:

$$\mathbf{W1} = \mathbf{L}(1\text{-}h/wb + H.d/\{wb.\cos\theta\} + H.\tan\theta/wb)$$
$$+ \mathbf{T}(1\text{-}c/wb + C.d/\{wb.\cos\theta\} + C.\tan\theta/wb)$$
$$+ \mathbf{W}kp(1\text{-} s/wb + Kp.d/\{wb.\cos\theta\} + Kp.\tan\theta/wb) \qquad \ldots(12)$$

$$\mathbf{W2} = \mathbf{L}(h/wb – H.d/\{wb.\cos\theta\} – H.\tan\theta/wb)$$
$$+ \mathbf{T}(c/wb – C.d/\{wb.\cos\theta\} – C.\tan\theta/wb)$$
$$+ \mathbf{W}kp(skp/wb – Kp.d/\{wb.\cos\theta\} - Kp.\tan\theta/wb) \qquad \ldots(13)$$

Total retardation force on the vehicle is $F = G1 + G2 – M.g.\sin\theta$. …(14)

11 Mass Distribution in an Axle Group.

The calculation distributed mass between the axle groups using the model described in Section 10. This mass is then distributed to axles within the axle group using the procedure described in this section.

ADVANCED MODE allows suspension brake reactivity to be modelled. This is achieved by specifying the Forward Mass Transfer Ratio (FMTR). The value selection is illustrated in the red dotted rectangle in Figure 14.

That is, the weight that is distributed to each axle in the group can be biased linearly to the front or to the back in the axle group.

Forward Transfer Mass Ratio (FMTR)

= Mass bias on Axle 1 when the deceleration = 0.5g. …(15)

If FMTR = 1.0, then every axle in the group has the same axle mass when the deceleration is 0.5g.

If FMTR = 1.1 then Axle 1 has a mass that 110% of the average axle mass when the deceleration is 0.5g. The distribution of mass to the last axle in the group will be 90% of the average axle mass.

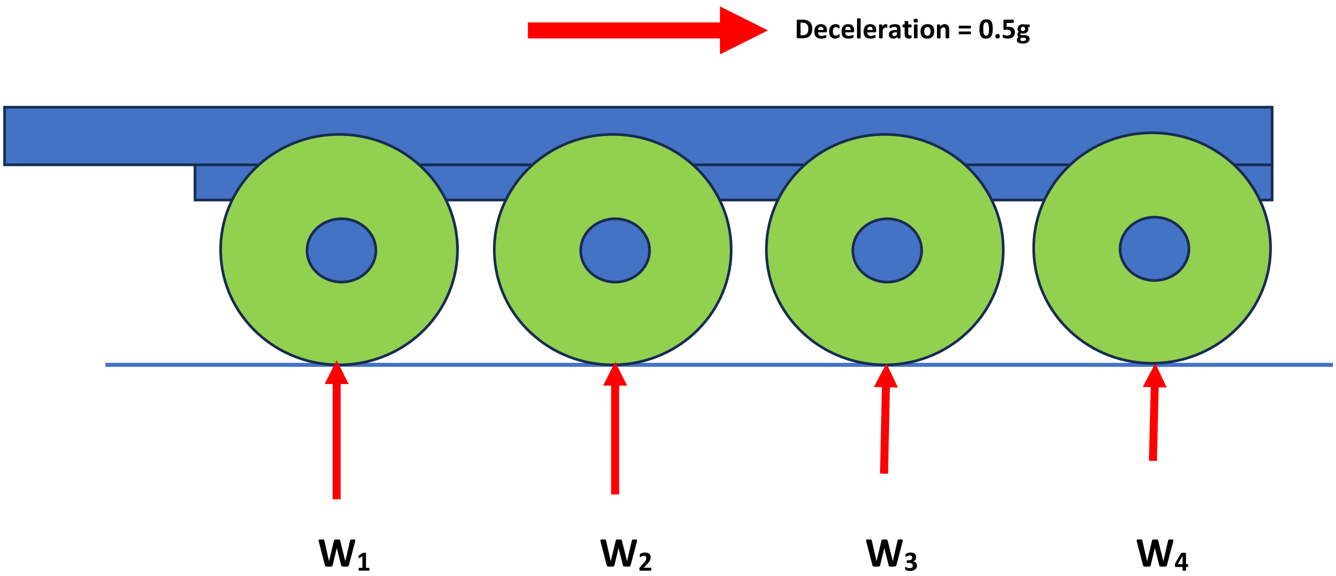
If FMTR = 0.9 then Axle 1 has a mass that 90% of the average axle mass when the deceleration is 0.5g. The distribution of mass to the last axle in the group will be 110% of the average axle mass.

The Average Axle Mass = Total Axle Group Mass (W) / Number of axles in the group (N).

The total mass on the axles is always W, which is calculated according to the

If the deceleration is zero, all axles are allocated the Average Axle Mass. For non-zero deceleration, the axle masses will be different depending linearly on the deceleration and on the position of the axle in the group and on the FMTR specified for Axle 1.

If the axle group has an odd number of axles, the axle in the centre position always has the Average Axle Mass irrespective of deceleration.



Axle Group Mass W = W1 + W2 + W3 + W4   (N=4 in this example)

Average axle mass = W/4.

Axle masses are allocated linearly depending upon the deceleration, position of the axle in the group and user-specified FMTR.

If FMTR is > 1, the axles in the first half of the axle group will get more weight than the average. and axles in the second half of the group will get less weight than the average.

Figure 18   Illustration of brake reactive mass allocation in ADVANCED MODE

11 Wheel Lock-Up Model

The tyre slip characteristic is assumed to apply to each tyre. The road friction is specified by the user. Typical values are 0.7 for a truck tyre on a dry road, 0.4 for a truck tyre on a wet road and 0.25 for a truck tyre on a loose surface gravel road.

Peak retardation occurs when the axle utilization Ni = Bi/ Gi = µ

Retardation Force i = Axle Pressure i x Torque at 1E / Ri = Bi …(16)

This assumes that all the braking force can be transferred to the road without slipping.

If the friction utilization Ɲi = (Bi – Si) / Gi of the axle > μ then the wheels will have locked up. The retardation force must be reduced because the calculated force cannot be applied to the road because the tyres will slip. The previously calculated force for which Ɲi ≤ μ is used as the basis for a force correction. The corrected force at this pressure level is:

Retardation Force i = Tyre Lock-up Factor x …(17)

maximum retardation force with Ɲi ≤ μ

The default value of Factor = 0.7. The user can change this value in the Settings section of the calculator. The user can also change the value of μ. By using a substantial value of Factor, the onset of wheel lock-up in an axle group becomes obvious on the utilization graphs. A disruption will be evident on an overwise straight line graph.

Because the friction utilization is only known at the calculation pressures, the peak tyre utilization is based upon the peak friction utilization that does not exceed μ. This may slightly under-estimate the peak point of the tyre friction curve (see Figure 19).

The locked-axle force is constant – that is does not change as the air pressure is increased, once wheel lock-up is determined.

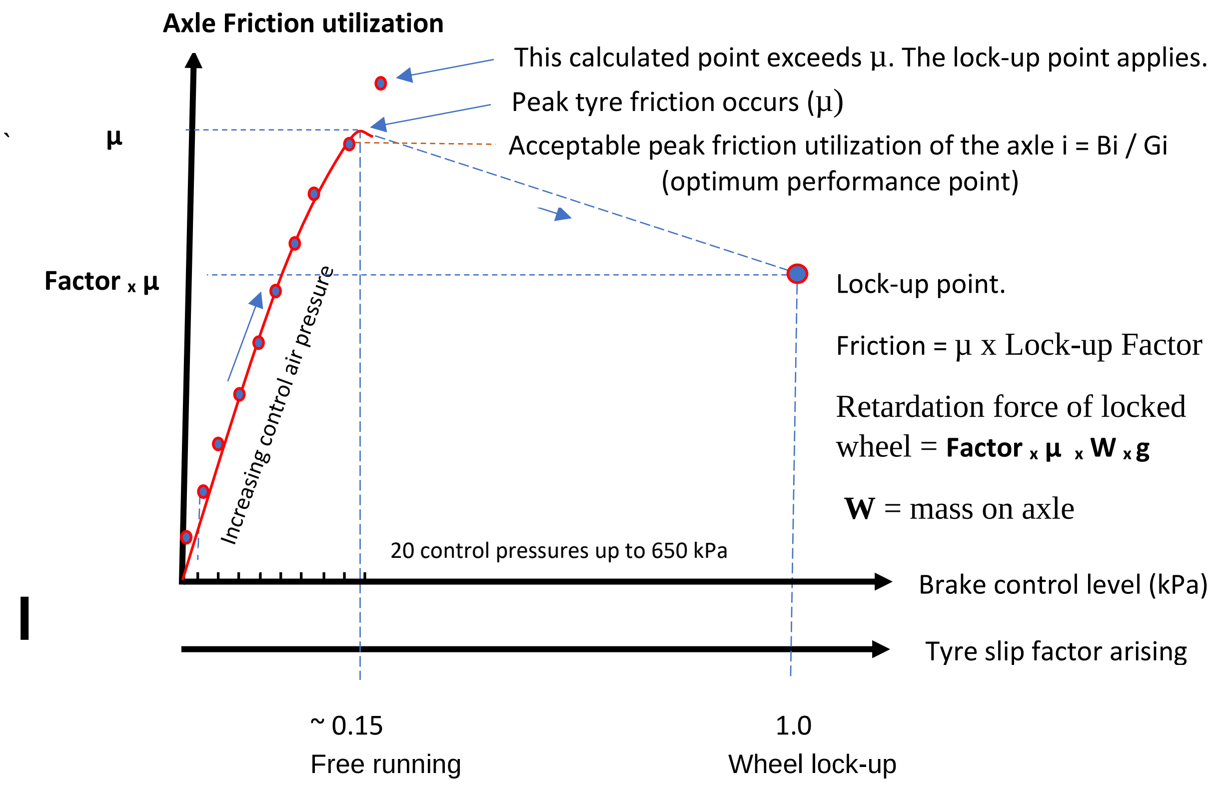


Figure 19 Wheel lock-up model characteristic

Tyre slip factor = (1 - tyre tread speed / Vehicle speed) …(18)

Locked-up Tyre Braking Force = **…**(19)

μ x Tyre Lock-up Factor x Lock-up Mass on Axle x g

There is no Anti-lock brake (ABS) model in the calculator. However, the user can alter the road-tyre friction level and the Tyre Lock-up Factor to model ABS operation. Antilock brakes have three operational modes, which are: no intervention, hold brake pressure and release brake pressure. During ABS cycling the brakes are released for some time, so there is a loss of braking effort. The user can model this loss of braking effort by changing both peak friction μ and Factor to a low level.

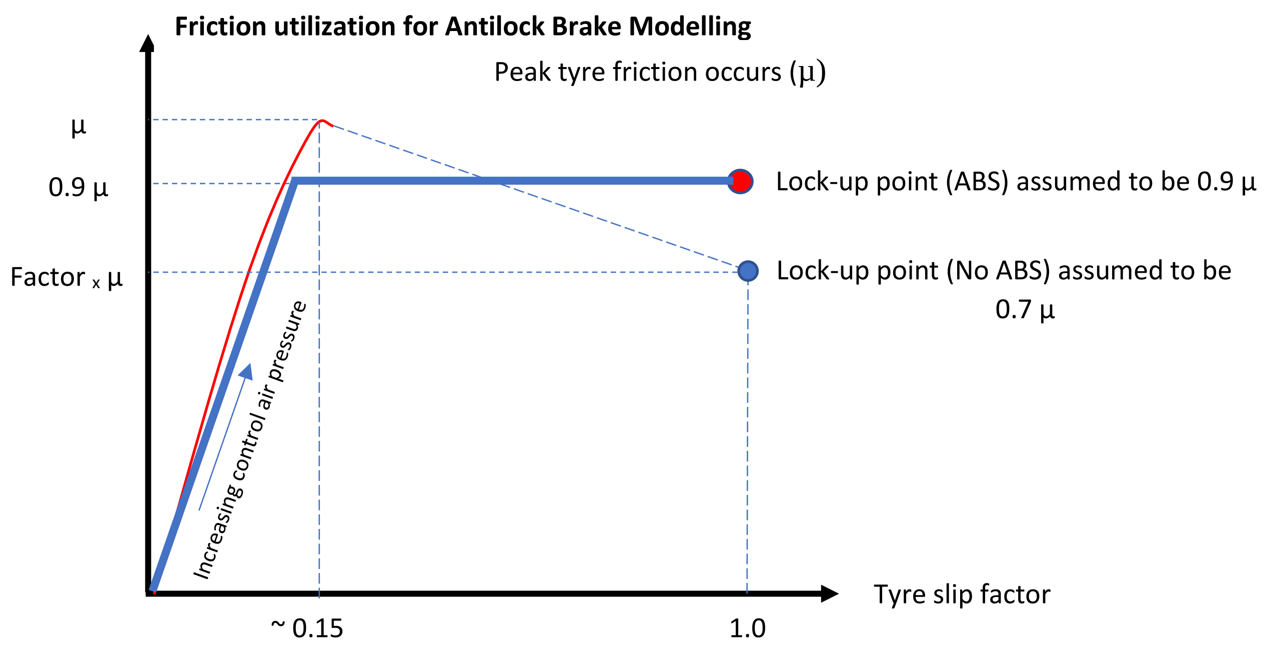


Figure 20 A possible ABS model.

In the ABS model that is illustrated in Figure 20, the road friction model is altered. The peak friction is now 0.9 μ and the lock-up friction is also set to 0.9. The settings for the ABS model are left to the User to determine.

Note on Vehicle Stability with Locked Wheels

The likely vehicle trajectory with locked-wheels (which are shown in black) are illustrated below:

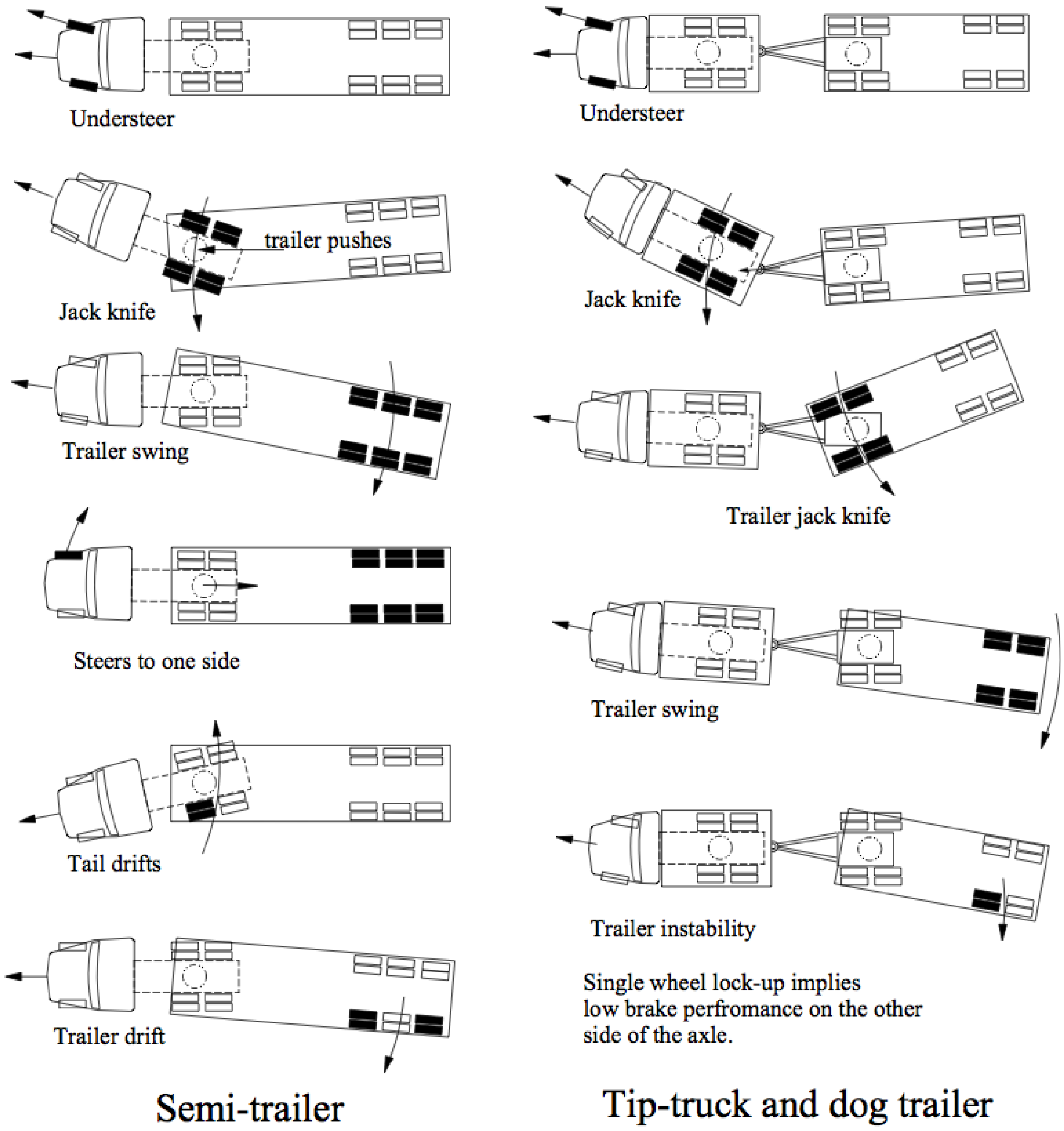


Figure 21 Likely dynamic movements of a semi-trailer (left) and a rigid truck with a dog trailer (right), with the locked wheels shown in black.

Wheel Lock-Up Limits in Various Australian Brake Rules

Australian Design Rule 38:

11.7. No trailer wheels must remain locked, except below 15 km/h, during completion of the braking tests required by clause 11.

17.2.2. No friction utilisation factor (F) must exceed 0.7 at z = 0.45 (a friction utilisation factor of greater than 0.7 is taken as to mean that wheel lock would have occurred in the physical test otherwise required by clause 11).

Trailer performance standard z = 0.45 from 60 km/h. (Truck performance standard z = 0.38 from 100km/h.)

PBS Technical Standard:

E5 DIRECTIONAL STABILITY UNDER BRAKING

E5.1 General

When demonstrated by simulation, a compliant vehicle must not have an instantaneous Friction Utilisation value on any axle group that exceeds 0.7 for any instantaneous vehicle deceleration up to and including the assessment deceleration levels given in Table 20.

Table 20. Deceleration levels for vehicles participating in the Scheme

Performance Based Standards Network Access Level	Typical vehicle configuration	Average Deceleration from 60 km/h
Single motor vehicles (All access levels)	Rigid trucks and buses	0.40 g
1	Semi-trailers	0.35 g
2	B-double combinations	0.30 g
3	Road-train A-doubles and B-triples	0.25 g
4	Road-Train A-triples	0.20 g

This applies to both laden and unladen vehicles.

Heavy Vehicle (Vehicle Standards) National Regulation:

(1) The braking system of a heavy motor vehicle built after 1930 or a heavy combination that includes a heavy motor vehicle built a 1930 must, on application of a brake, be able to produce the performance mentioned in subsections (2) to (4)—

(a) when the vehicle is on a dry, smooth, level road surface, free from loose material; and

(b) whether or not the vehicle has goods or passengers in it; and

(c) whether or not the vehicle is used alone or as part of a combination; and

(d) without part of the vehicle moving outside a straight path—

(i) centred on the longitudinal axis of the vehicle before the brake was applied; and

(ii) 3.7m wide.

(3) The braking system of a heavy motor vehicle or heavy combination that includes a heavy motor vehicle built after 1930 must decel the vehicle, from any speed at which the vehicle can travel, by an average of at least—

(a) 2.8m a second a second when the service brake is applied; and

Note on Brake System Design to Minimise Wheel Lock-Up

Wheel lock-up is detrimental to vehicle stability because a locked tyre cannot provide the same level of braking or cornering forces that a rotating wheel can. Therefore, the brake design on a vehicle should achieve good brake distribution balance on each vehicle part and good combination brake balance between vehicle parts. Good brake balance shares the braking effort and avoids a few wheels doing too much braking. The relevant index is axle friction utilisation, which should be about the same on all axles. Achieving good brake balance is particularly challenging on a lightly laden vehicle unless the braking effort is reduced as the load is reduced. That is, unless the brake systems are adaptive.

The forces and moments produced during heavy braking tend to transfer the weight forward. The forward axle group gets increased load and the rear axle group less load. Therefore, the friction utilisation of the rear axle group tends to increase. Wheel lock-up is more likely on the rear wheels than the front wheels. Wheel lock-up that occurs on the rear wheels first is less dangerous than on the front wheels first, because poor dynamics that could result tends to happen slower. It is desirable to have the same friction utilization on all the axles on a vehicle with the load at zero height. Once the load is set at true height, the utilization will be greater on the rear axles.

12 Deceleration Calculation Procedure

Because wheel lock-up depends upon axle weight and hence deceleration, the calculation procedure must be iterated.

The procedure is:

Deceleration calculation as a function of control air pressure.

First Iteration

a) The air pressure at each axle is calculated for each of the twenty control air pressure levels.

b) Assuming no wheel lock-up occurs, the brake torque on each axle and then the retardation force on each axle is calculated. An estimate of the vehicle deceleration is obtained. At this stage it is assumed that no tyres have locked up. (‘first deceleration estimate’)

c) The weight distribution on each axle is calculated for the first estimate of the vehicle deceleration (obtained from step (b)). (‘first axle weights estimate’). The calculation uses equations (12) & (13).

d) The friction utilization of each axle Ɉi = (Bi – Si) / Gi is calculated because first estimates for: tyre retardation force, tyre slope force on each axle and the axle weight exist.

e) The total vehicle deceleration is calculated by dividing the total vehicle (estimated) retardation force by the total vehicle mass.

Second Iteration

f) If the friction utilization of tyres on an axle exceed the available road friction Ɉi > μ, then the retardation force at that axle is reduced to the value stated in Equation (19).

g) Because the axle retardation forces may have changed due to step (f), a new estimate of vehicle deceleration is obtained by dividing the total vehicle retardation force by the total vehicle mass. (‘second deceleration estimate’).

h) The weight distribution on the axles is recalculated using the second deceleration estimate. (‘second axle weights estimate’). The calculation uses equations (12) & (13) with the revised deceleration. The weight is distributed within the axle group according to the procedure in Section 11.

i) The friction utilization of each axle is recalculated using the forces from step (g). and the weight estimates of step (h).

j) Using the revised friction utilization values for each axle, a new assessment of whether the wheels on an axle have locked-up or not is made.

Third Iteration

k) The axle retardation forces are recalculated using the new assessments of wheel lock-up.

l) Because the axle retardation forces may have changed due to step j, a new estimate of vehicle deceleration is obtained. (‘third deceleration estimate’).

m) The weight distribution on the axles is recalculated using the third deceleration estimate. (‘third axle weights estimate’). The calculation uses equations (12) & (13) with the revised deceleration. The weight is then distributed within the axle group according to the procedure in Section 11.

n) The friction utilization of each axle is recalculated using the forces from step (l) and the weight estimates of step (m). The axle retardation forces are calculated using Equation (19) based upon these latest friction utilization estimates.

Final Calculations

o) The calculation ceases when the third (and final) estimate of deceleration is obtained for each of the twenty control pressure levels. Deceleration equals the total (final) axle retardation forces divided by the total vehicle mass.

p) The graphs are created for axle service brake utilization as a function of the control pressure.

q) The stopping distance can then be calculated as explained in the next section.

13 Stopping Distance Calculation Procedure

Once the vehicle deceleration **d** has been calculated for each control air pressure, the stopping distance is calculated as follows:

$$\textbf{Stopping distance} = V^2/2d + V \times \text{Driver delay} + V \times \Delta T_{av} \times P/P_{1E} \qquad \ldots(23)$$

V = initial speed in m/s.

D = average deceleration (m/s^2) calculated for the control pressure level being considered, which is P.

P is the control pressure level.

P_{1E} = 650kPa.

ΔT_{av} is the average time delay of the vehicle combination, which is the weighted average of all the axle group time delays that have been specified by the user. The weighting is based upon the relative static weight of the axle group normalised by the combination vehicle static weight. The time delays relate to the time taken to reach 650kPa (1E). Consequently, the delay is proportioned in Equation (23), taking account of the actual control pressure level P.

The Driver delay time is specified by the user under the parameters set-up (Section 4). It is the time taken for the driver to apply the service brakes. This feature is provided for users interested in calculating stopping distances for crash reconstruction purposes where driver reaction time is relevant.

14 Wheel Lock-up Indication

On the Results Summary page: brake control levels for which axle group wheel lock-up occurs on a vehicle are not shown. In the example shown in Figure 22, the friction utilization exceeds μ (hence wheel lock-up is occurring) for brake control pressures 163kPa and above for the unladen vehicle and 260kPa and above for the laden vehicle.

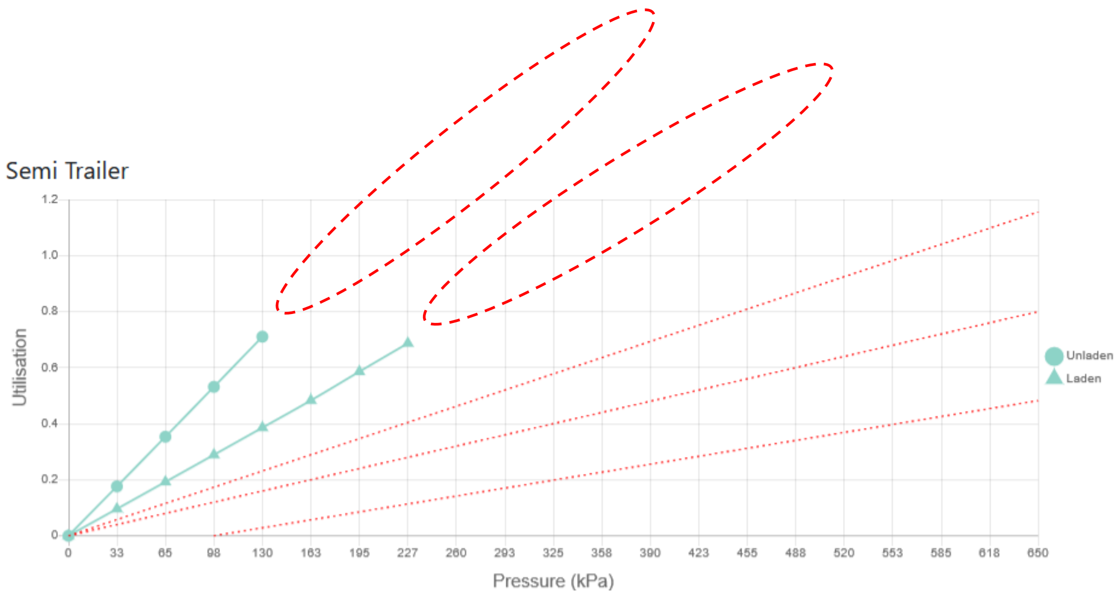


Figure 22 Example of lock-wheel suppression

15 Parking Brake Calculation

The parking performance can be calculated for the specified slope. ADRs 35/0* & 38/0* require each vehicle to hold the axle engineering-rated mass on an 18% grade (10.2^{o}).

The parking brake retardation force is applied to the roadway via the tyres. Therefore, tyre slip needs to be considered. The tyre-slip / wheel lock-up model is also applied to park-brake performance.

Deceleration is not relevant to parking brake performance. Therefore, the wheel lock-up model is less complicated than it is for the dynamic calculation. The calculation procedure is:

Once the parking brake torque is calculated for each axle that has parking brakes, the parking retardation force is calculated:

Parking Force for axle group i = Brake axle parking torque / Tyre radius …(20)

However, this equation assumes that the tyre does not slip along the roadway. Therefore, tyre slip needs to be checked and allowed for.

The weight distribution between axle groups for parking is calculated using Equations (12) & (13), with deceleration = 0. This weight is distributed between axles in the group equally. Each axle in the group carries weight **Gi**.

The friction utilization of each axle that has a parking brake is calculated using Ɲi = Bi / Gi.

If **Ɲi** > **μ** then the tyres will slip on the surface. The axle parking force is then set to the value:

$$\textbf{Parking Force for axle group i} = \mu \cdot Gi \qquad \ldots(21)$$

If not all axles in a group have parking brakes, enter Advanced Mode and set the parking brake on some axles to zero (see Figure 14 in Section 6 for an illustration of how to do this). There will be no parking brake force contribution from axles that have zero parking brake torque specified. They will still carry their share of the group weight.

The program determines whether the sum of all the parking brake forces, which are calculated using Equation (20) or (21) as applicable, is greater or less than the vehicle slope force. If it is greater than the slope force for the specified grade, the vehicle will hold.

The above-mentioned calculation process is summarised as follows:

Net Parking Brake Force Calculation

1. The parking brake performance is calculated using the brake torque specified for each axle that has parking brake actuators.
2. The force at each axle with parking brakes is calculated using the specified brake torque applied through the specified tyre radius.
3. The (static) weight distribution at each axle is calculated assuming zero deceleration. This calculation assumes at 18% grade, unless the user specifies another grade.
4. The axle utilization is calculated for each axle with parking brake actuators.
5. If the friction utilization of tyres on an axle exceeds the available road friction Ɲi > μ, then the retardation force at that axle is reduced to the value stated in Equation (17).
6. The net parking brake force is calculated using the sum of the forces calculated at step u with the vehicle slope force due to gravity subtracted. The net parking brake force is graphed. If this is positive, the vehicle will hold. If it is negative, the vehicle will slide.
7. The net parking brake force is calculated for both the unladen vehicles and the laden vehicles.

The parking brake torque values that are reported in the foundation brake library are as shown on the CTA or CRN approvals. These values should be carefully reviewed by the User as many have been declared to be equal to the foundation brake torque at 1E control level, which is unrealistic. The parking brake torque generated by a spring brake, is the static torque associated with the actuator spring force. The actuator spring force is indicated by the air pressure needed to just hold off the actuator spring. As a guide this pressure is about 0.5E. Therefore, a guide to parking brake torque is half the stated service brake torque at 1E control level.

16 Trailer-Only Calculations

The calculator has a trailer-only modules. This allows one trailer to be calculated without any towing vehicle being involved. Therefore, the total weight of the vehicle is the weight of the trailer.

The User can select either:

- Semi-trailer only module (which can also be used for a centre-axle group trailer)
- Dog-Trailer only module (which is a trailer with a front and a rear axle group).

Because the towing vehicle has no mass, the total trailer mass is used to calculate the deceleration. For the Dog trailer, there is no weight transfer onto the towing vehicle. The trailer utilization equals the vehicle deceleration.

For the semi-trailer, there is weight transfer onto the towing vehicle (which has no mass and no brakes). The axle group utilization will differ from the deceleration because the weight on the axle group is different to the trailer weight.

ADR 38/05 requires the Established Retardation Coefficient to be calculated. This is defined as follows:

17.3.2. The *'Established Retardation Coefficient'* must be calculated by:

$$\mathrm{ERC} = \frac{\text{total brakeforce at e}}{'\textit{Total Trailer Axle Load}'} = \frac{e\left[\frac{C_1T_1}{R_1} + \frac{C_2T_2}{R_2} + \text{etc.}\right]}{(P_1 + P_2 + \text{etc.})}$$

where:

e is the value of *'E'*

C is the ratio of output Signal Level to *'Control Signal'* strength for the *'Control System'* for the *'Axle'* concerned

T is the *'Brakes'* output torque per unit input signal to the *'Brakes'* actuator from output of the *'Control System'* for the *'Axle'* concerned

R is the rolling radius of the tyre on the wheel

P is the static load on the *'Axle'* concerned

1, 2, etc. are subscripts referring to the concerned *'Axle'*

'Total Trailer Axle Load' in tonnes with the trailer loaded as specified in clause 10.6

Figure 23 Definition of ERC in ADR 38/05.

ERC is calculated with the static axle mass and the total brake force, which for a semi-trailer is the brake force from its single axle group. This calculation requires that the static axle mass be used and not the dynamic axle mass. To achieve this the User can set the heights of the tare and load masses above the axle centre line to zero. This turns off the load transfers as required by the ERC calculation. However, the calculator provides both the ERC calculation and the load-transfer calculation separately, so the User need not 'trick' the calculation.

Figure 24(a) & (b) show a comparison for an exemplar semi-trailer with three axles, each with 18.5kN disc brakes. Figure 24(a) show the results for no load transfer. Figure 24(b) shows the results with load transfer. As expected, the utilization of the rear axle group is higher with load transfer than without load transfer, because in the later case, some of the mass on the axle group transfers to the towing vehicle.

This trailer has one axle group. The ERC for the vehicle is the rear axle group utilization with no load transfer, so that the weight on the axle is not dependent on brake level. The trailer-only modules have an ERC graph option. The option can be seen in Figure 24(a).

The deceleration (including wheel lock-up) and the ERC for the example are shown separated Figure 24(b). The graphs are substantially different when wheel lock-up exists.

Onset of wheel lock-up

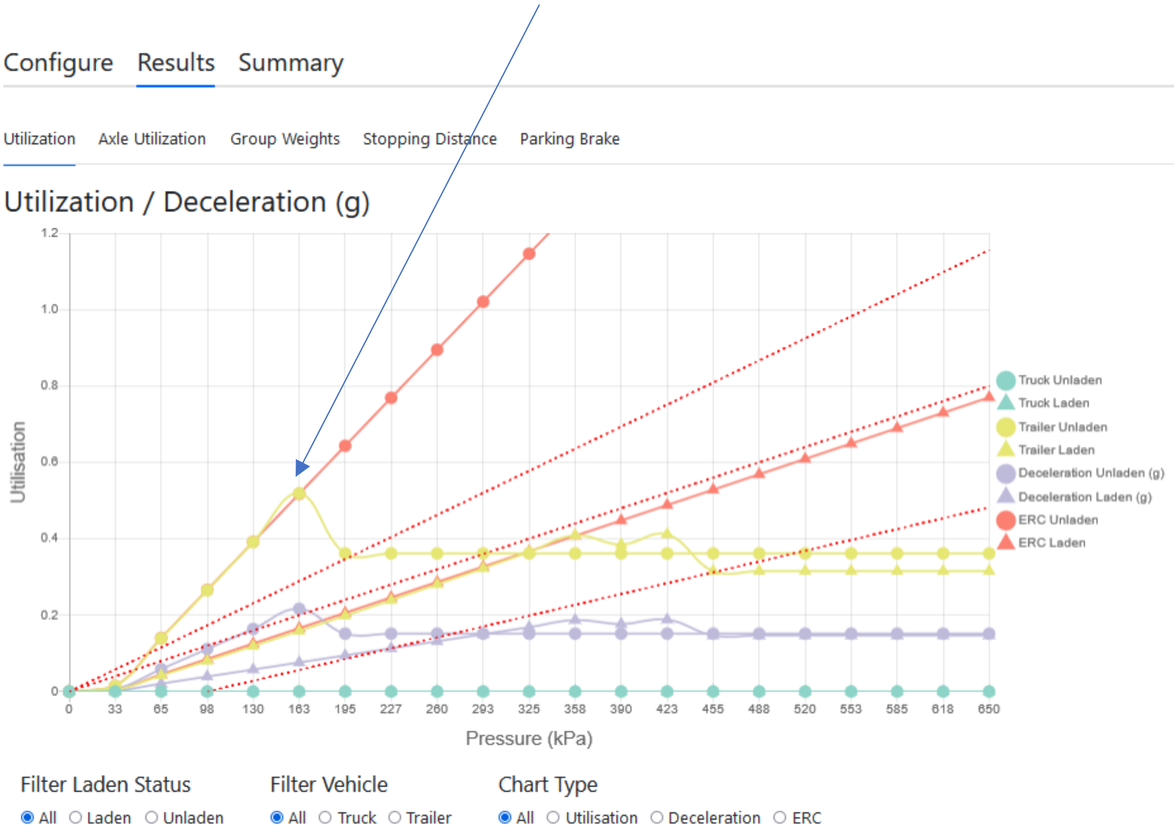
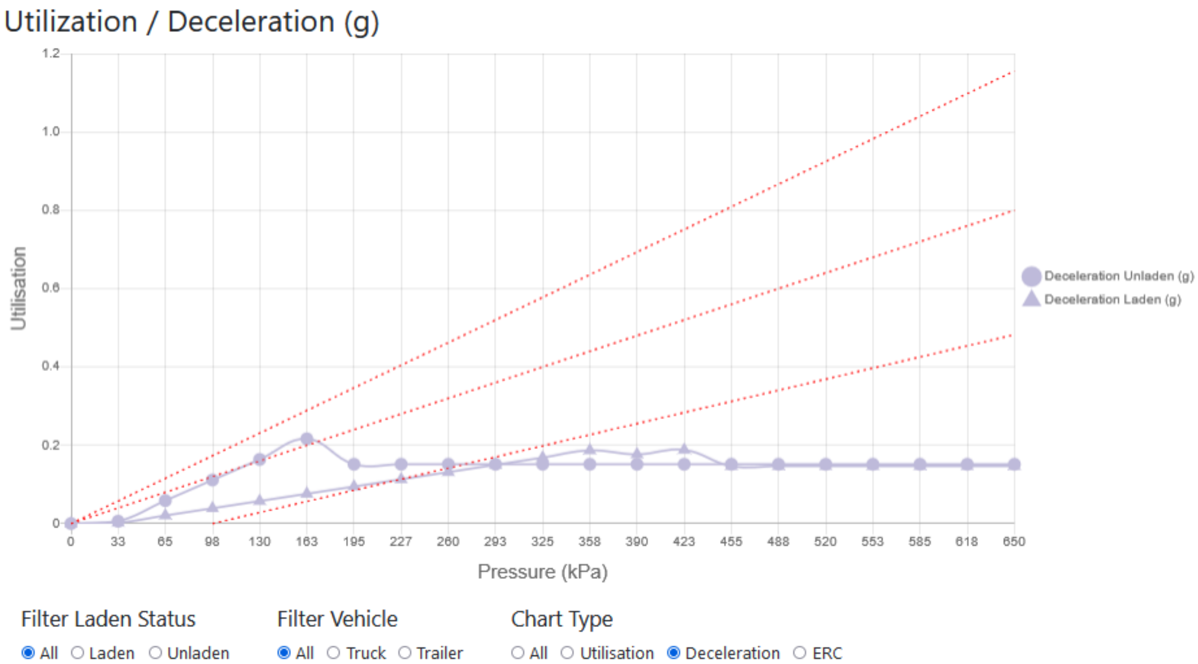


Figure 24(a) Example semi-trailer performance with without load transfer

Both truck and trailer vehicles are shown.

Tare = 6t at zero height
Load = 24t at zero height.



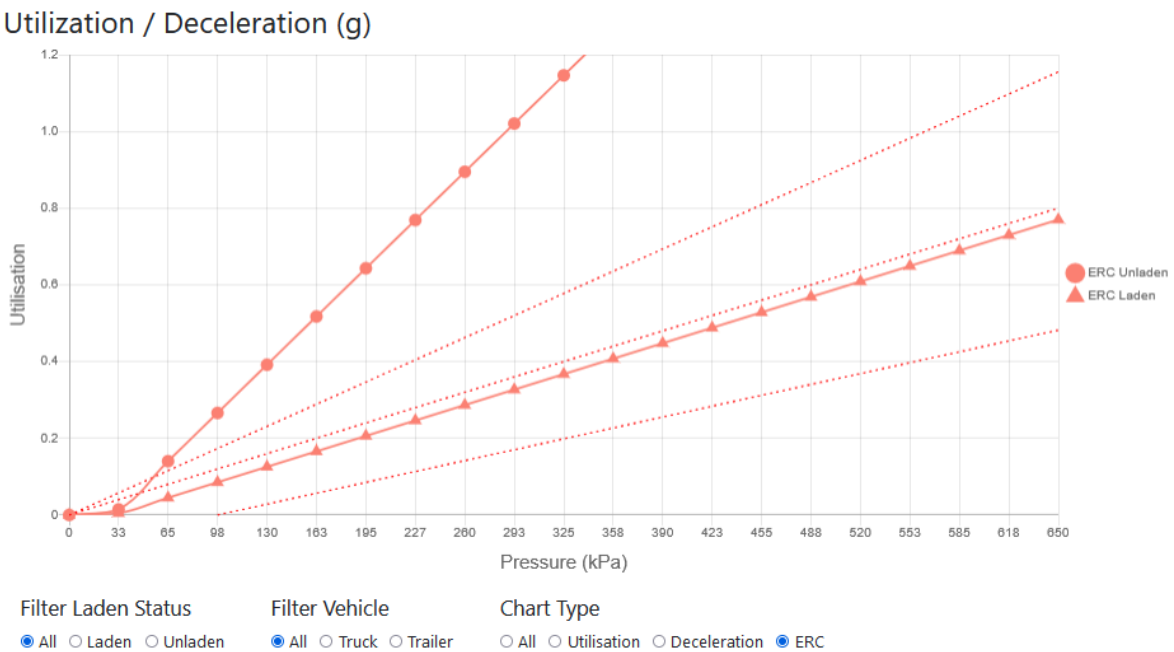


Figure 24(b) Example semi-trailer performance with load transfer

Tare = 6t at 0.5m height
Load = 24t at 2.5m height.

17 Emergency Brake Calculation

Emergency brake performance can be calculated if the emergency brakes can be quantified as a percentage of the service brake level. For heavy trucks and trailers the emergency brakes are the spring brakes and the brake elements are shared with the service brakes. The torque available from the spring actuators is approximately equal to the service brake performance at the hold-off pressure level for the brake actuators that are used. For example, if the air pressure needed to hold the spring brakes off is 325 kPa, then the expected spring-brake performance is that of the service brake at 325 kPa (0.5E).

If an accurate torque level for each emergency brake is unknown, the user can predict the performance of the emergency brakes by using the calculated values for the service brakes at 0.5E brake control level. The calculation takes account of wheel lock-up. Note that if the number of spring brakes in an axle group is less than the number of service brakes, the service brake torque on the axle without spring brakes must be set to zero because there is no brake on that axle. This can be done in Advanced Mode – See Figure 25.

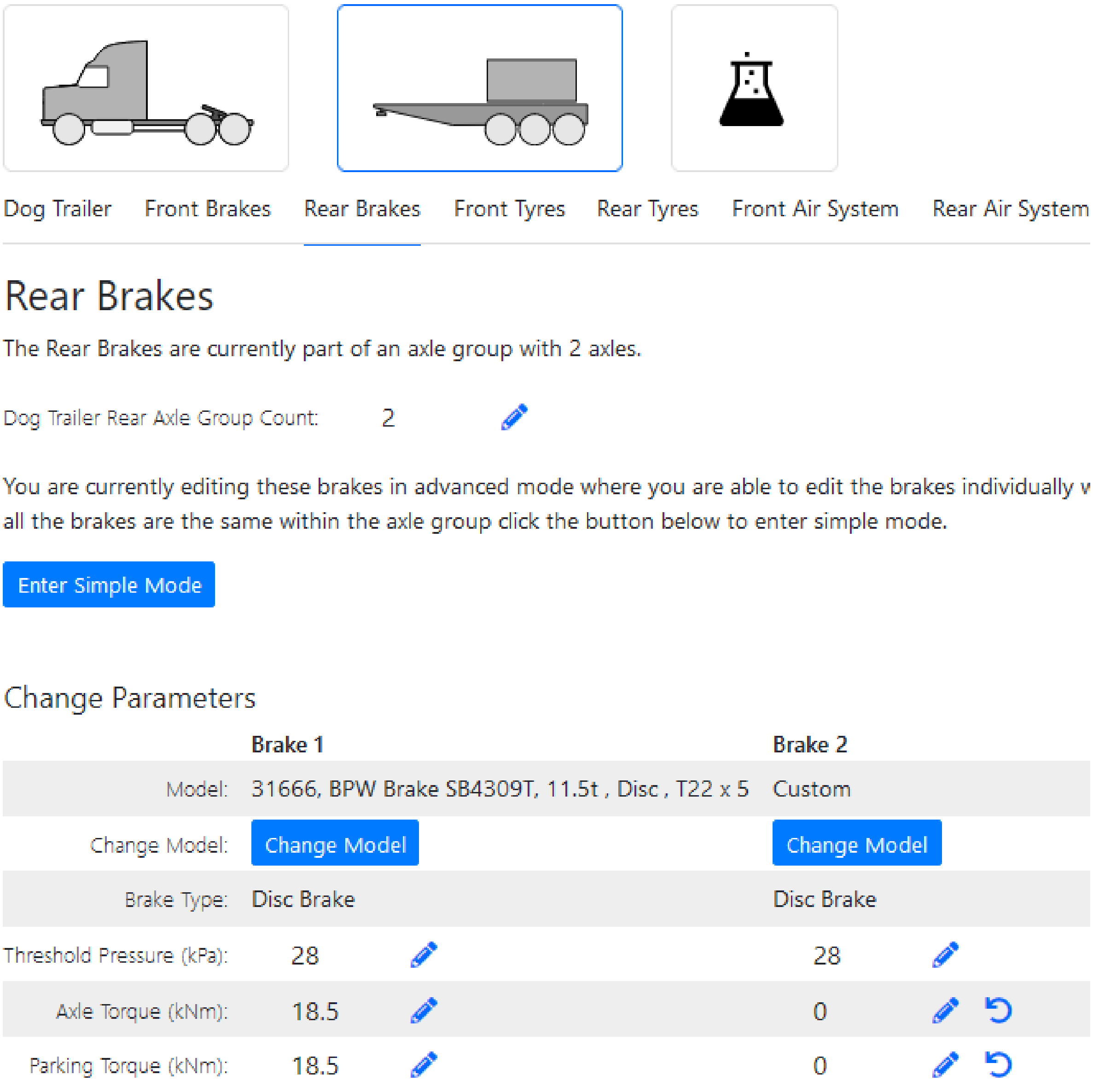


Figure 25 Example of setting different brake performance on different axles in a group (Advanced Mode)

18 Results Summary

The Summary tab provides a complete summary of the vehicle specification and its results. The results are presented as graphs for each vehicle separately. Examples of the output graphs available are shown in Figures 26 & 27.

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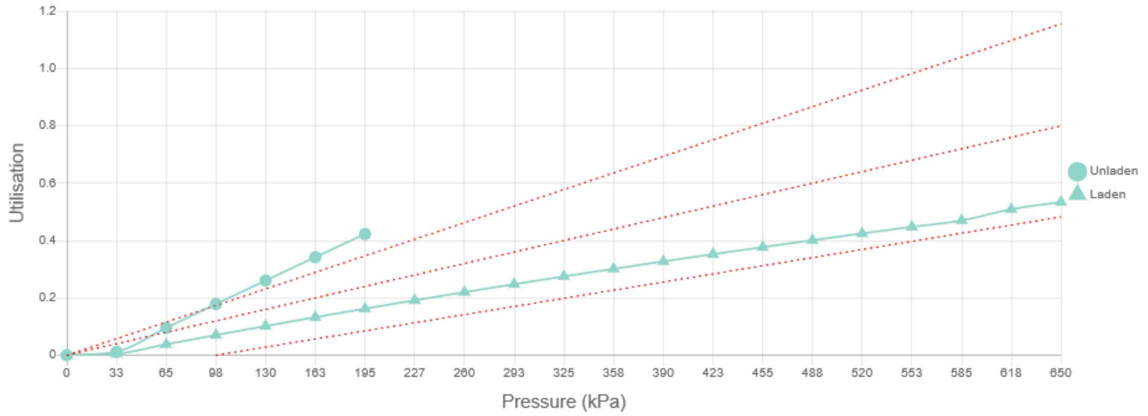
Rename Delete

Configure Results Summary

Prime Mover

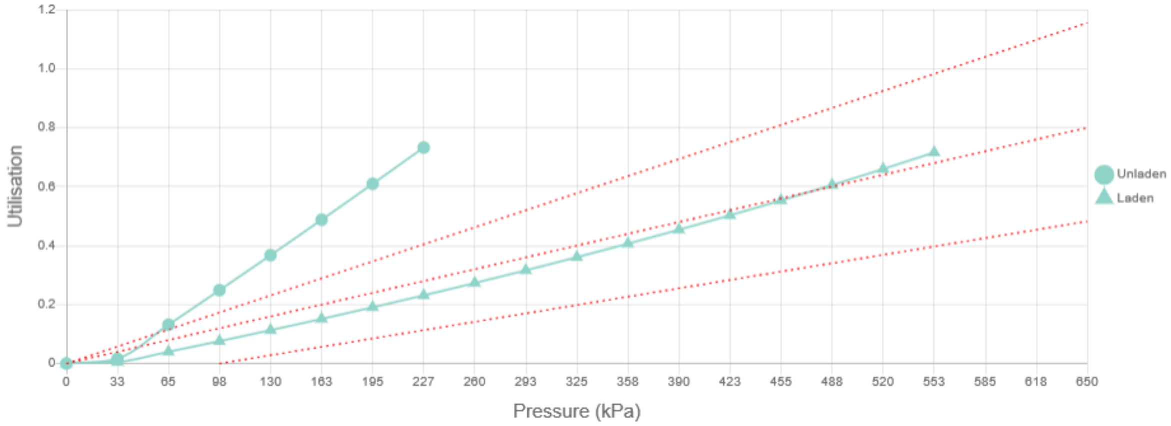


Prime Mover

Model	Generic 3-Axle Prime Mover
Height of Centre of Mass (m)	1
King Pin Height (m)	1.5
King Pin Location (m)	5.5
Wheel Base (m)	6
Front Tare Group Weight (t)	4
Rear Tare Group Weight (t)	3
Front Axle Group Count	1
Rear Axle Group Count	2
Pressure Time Delay Until 420kPa (s)	0.3

Figure 26 Example of Summary tab output for the prime-mover in a semi-trailer configuration.

Semi Trailer



Semi Trailer

Model	Generic 3-Axle Sem itrailer
Height of Centre of Mass (m)	0.5
Trailer Length (m)	8.53
Tare Group Weight (t)	5.5
Unladen Weight (t)	6
Axle Count	3
Pressure Time Delay Until 420kPa (s)	0.3

Trailer Brakes

	Brake 1, 2, 3
Model	CRN-31666, BPW Brake SB4309T, 11.5t , Disc , T22 x 5
Brake Type	Disc Brake
Threshold Pressure (kPa)	28
Axle Torque (kNm)	18.5
Parking Torque (kNm)	18.5

Figure 27 Example of Summary tab output for the semi-trailer in the configuration

The axle group and individual axle utilisation graphs are not available under the Summary tab. Axle-level utilisation is only reported under the Results tab. For example, the friction utilisation for individual axles in a group for a B-double vehicle is shown in Figure 28.

Figure 28 Example of Results tab output for the a B-double vehicle.

19 Brake Application Pressure Graph

The user is required to specify the threshold air pressure for each foundation brake (see for example Figure 13). The threshold pressure is the air pressure required for the brake to produce retardation torque to overcome friction and resilience in the brake foundation brake mechanism.

The control air pressure required to provide the threshold air pressure at each foundation brake could be different (higher) because of air valve characteristics. The user can specify an air transfer characteristic involving a piecewise linear transfer characteristic between the front control air-port on a vehicle and each axle group on each vehicle. An example of this feature is shown in Figures 15 & 16.

A graph of the ‘Effective Threshold pressures’ is available on the Results page – see Figure 29. This shows the effective threshold pressure at each axle taking account of all the air transfer ratios in the control path to that axle. An example is shown below. In this example the front axle will wear out much faster that the rear trailer axles because it will be involved in all the low-pressure braking (less than 100kPa) whereas the rear trailer brakes will scarcely be involved.

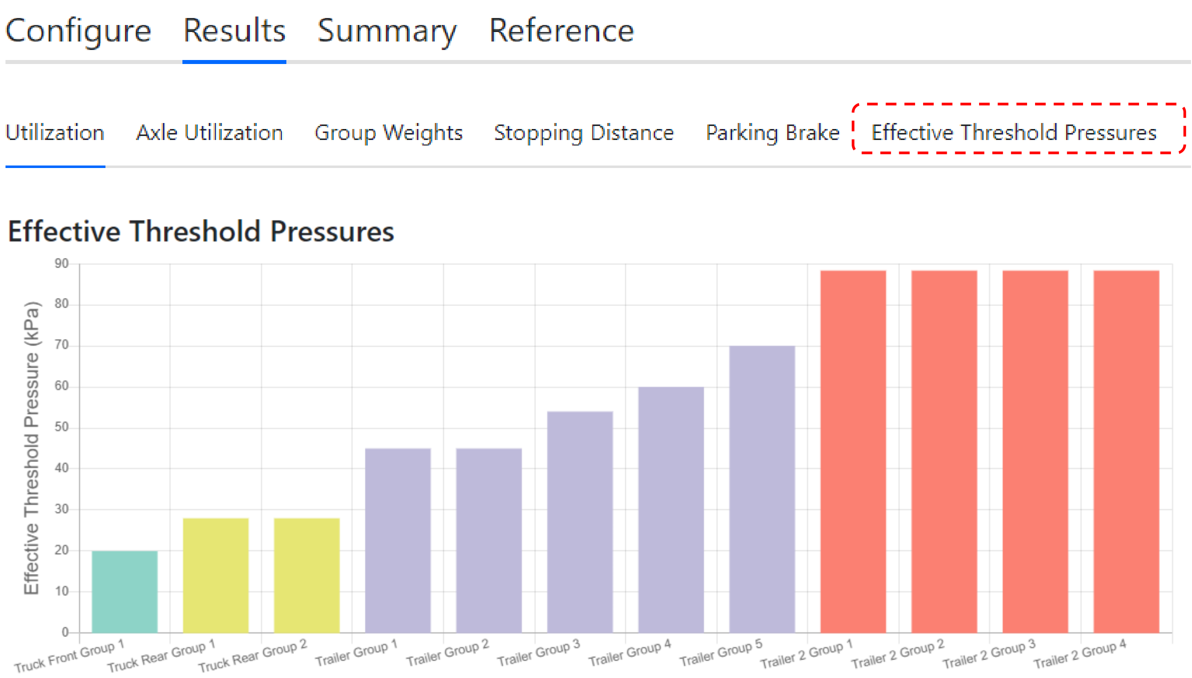


Figure 29 Graph of effective threshold pressures for a B-double combination.

Appendix 1 – Dimensions Used in the Calculator

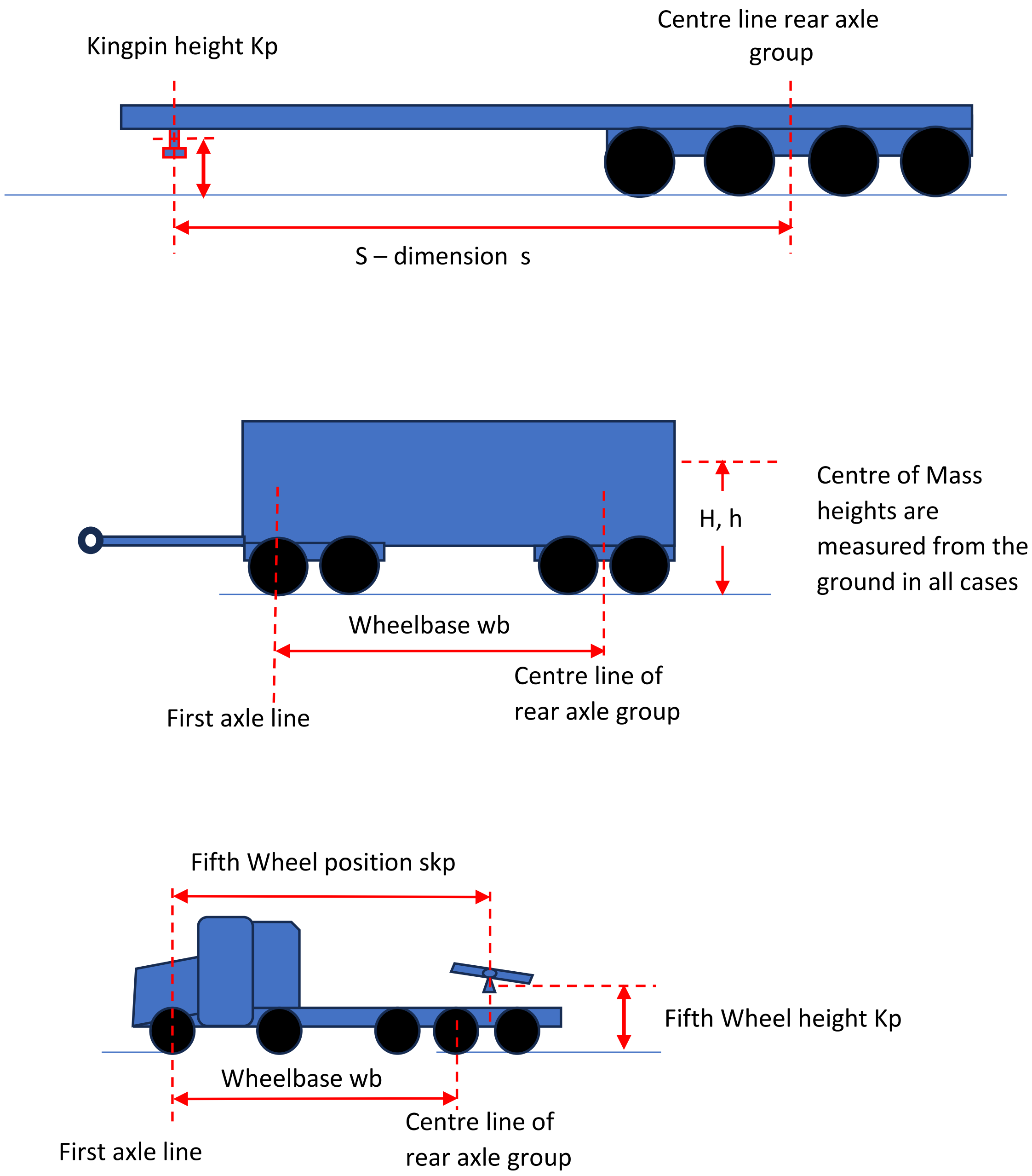


Figure A1 Illustration of dimensions used in the calculator

Appendix 2 - Vehicle Specifications

To assist the user to quickly configure a vehicle, 'Generic' vehicle settings can be selected as shown in the following Figures. These figures also serve to indicate the range of parameters that need to be specified. The user can override any of the generic selections.

Prime Mover

Name:	Generic 3-Axle Prime Mover
Height of unladen centre of gravity in metres:	1.0
Height of king pin in metres:	1.5
Location of king pin in metres:	5.5
Wheel base length in metres:	6.0
Front tare group weight in kilograms:	4.0
Rear tare group weight in kilograms:	3.0
Front tare group axle count:	1
Rear tare group axle count:	2
Pressure time delay to 420kPa:	0.3

Figure A2

Name:	Generic 4 Axle Prime Mover
Height of unladen centre of gravity in metres:	1.0
Height of king pin in metres:	1.5
Location of king pin in metres:	5.5
Wheel base length in metres:	6.0
Front tare group weight in kilograms:	4.0
Rear tare group weight in kilograms:	3.0
Front tare group axle count:	2
Rear tare group axle count:	2
Pressure time delay to 420kPa:	0.3

Figure A3

Semitrailer

Note that a centre-axle trailer model can be obtained by specifying the centre axle group to be approximately in the at the centre point of the semi-trailer.

Name:	Generic 3-Axle Sem itrailer
Height of centre of mass above axle in metres:	0.5
Length in metres:	8.53
Tare group weight in kilograms:	5.5
Unladen weight in kilograms:	6.0
Axle count:	3
Pressure time delay to 420kPa:	0.3

Name:	Generic 4-Axle Semi trailer
Height of centre of mass above axle in metres:	0.5
Length in metres:	8.53
Tare group weight in kilograms:	5.5
Unladen weight in kilograms:	6.0
Axle count:	4
Pressure time delay to 420kPa:	0.3

Figure A4

Rigid Truck

Name:	Generic 3-Axle Rigid Truck
Height of centre of mass above axle in metres:	0.7
Length in metres:	6.0
Front tare group weight in tons:	3.0
Rear tare group weight in tons:	3.0
Front axle count:	1
Front axle count:	2
Pressure time delay to 420kPa:	0.3

Figure A5

Name:	Generic 4-Axle Rigid Truck
Height of centre of mass above axle in metres:	0.7
Length in metres:	6.0
Front tare group weight in tons:	3.0
Rear tare group weight in tons:	3.0
Front axle count:	2
Front axle count:	2
Pressure time delay to 420kPa:	0.3

Figure A6

Dog Trailer

Name:	Generic 3 Axle Dog
Height of centre of mass above axle in metres:	0.5
Length in metres:	6.0
Front tare group weight in tons:	7.0
Rear tare group weight in tons:	7.0
Front axle count:	1
Rear axle count:	2
Pressure time delay to 420kPa:	0.3

Figure A7

Name:	Generic 4 Axle Dog
Height of centre of mass above axle in metres:	0.7
Length in metres:	6.0
Front tare group weight in tons:	7.0
Rear tare group weight in tons:	7.0
Front axle count:	2
Rear axle count:	2
Pressure time delay to 420kPa:	0.3

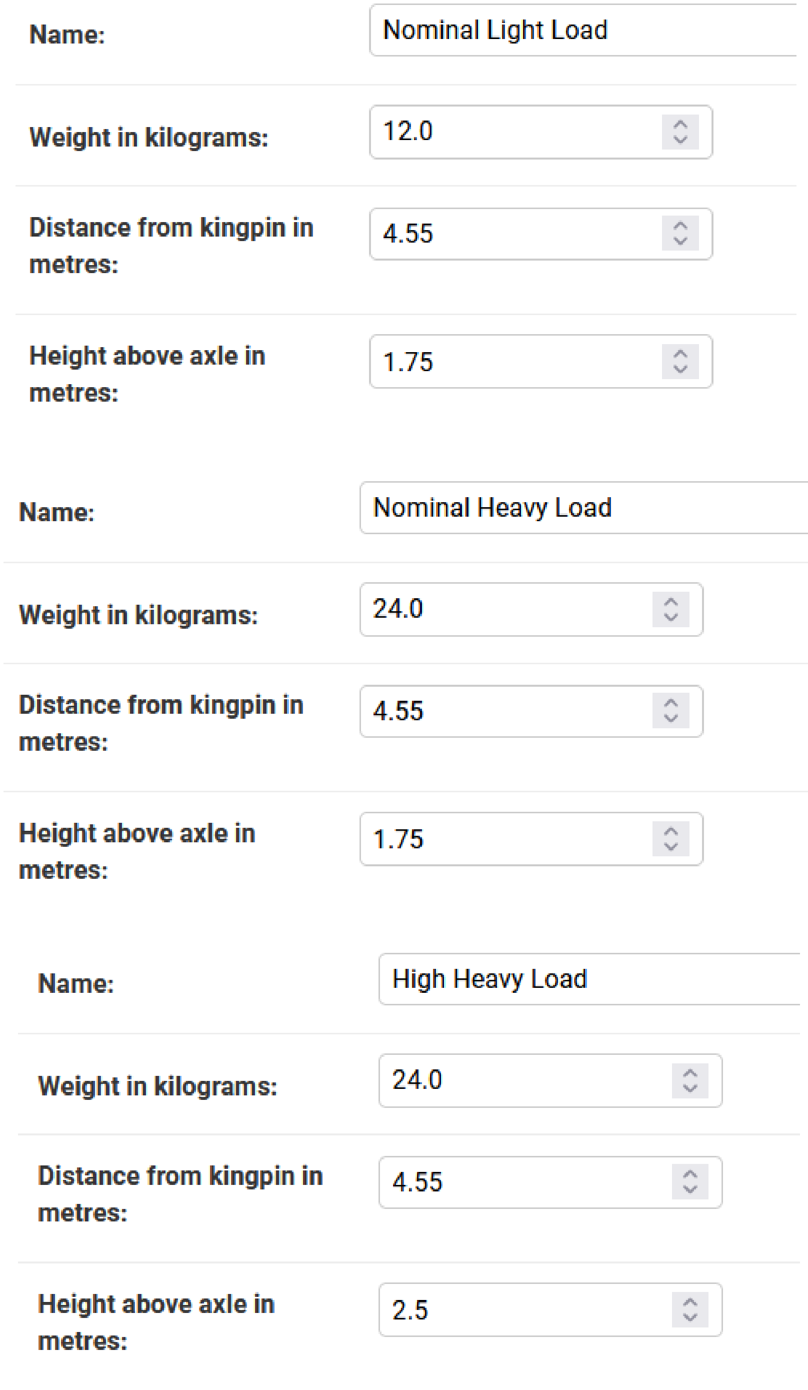
Figure A8

B-Double Trailers

Two Generic semi-trailers can be used for this specification.

Appendix 3 Generic Load Settings

The available load settings are shown below. The user can respecify any of the parameters:



Name:	Nominal Light Load
Weight in kilograms:	12.0
Distance from kingpin in metres:	4.55
Height above axle in metres:	1.75

Name:	Nominal Heavy Load
Weight in kilograms:	24.0
Distance from kingpin in metres:	4.55
Height above axle in metres:	1.75

Name:	High Heavy Load
Weight in kilograms:	24.0
Distance from kingpin in metres:	4.55
Height above axle in metres:	2.5

Figure A9

The High Heavy Load has a higher centre of load height than the Nominal Heavy Load.

Appendix 4 Refence Calculation for B-Double Truck

A3.1   No Wheel Lock-up

Prime mover weight = 6t.   Tyre radius = 0.448324m All brakes = 18.5 kNm/axle

No load transfer and no wheel lock-up is achieved by setting μ = 5.

Trailer 1 tare weight = 6t at 0 height. Trailer 2 tare weight = 6t at 0 height

Trailer 1 load weight = 10t at 0 height. Trailer 2 load weight = 10t at 0 height.

Trailer has three axles with the same brakes and tyres as the prime-mover. All brakes = 18.5 kNm/axle.

Vehicle service brake force = 9 x 18.5 / 0.448324m = 371.387kN (at 1E brake control).

<u>Newton's Second Law</u>

Unladen with no load height

Newton deceleration at 325kPa (E/2):   (325/650)*371.387/18 = 10.3162 m/s^2 (1.052g)

Calculator result = 1.05g.

Laden with no load height

Newton deceleration at 325kPa: (325/650)*371.387/38 = 4.887 m/s^2 (0.498g)

Calculator result = 0.50g.

Conclusion: The calculator gives the same result as Newton's second law to two significant figures.

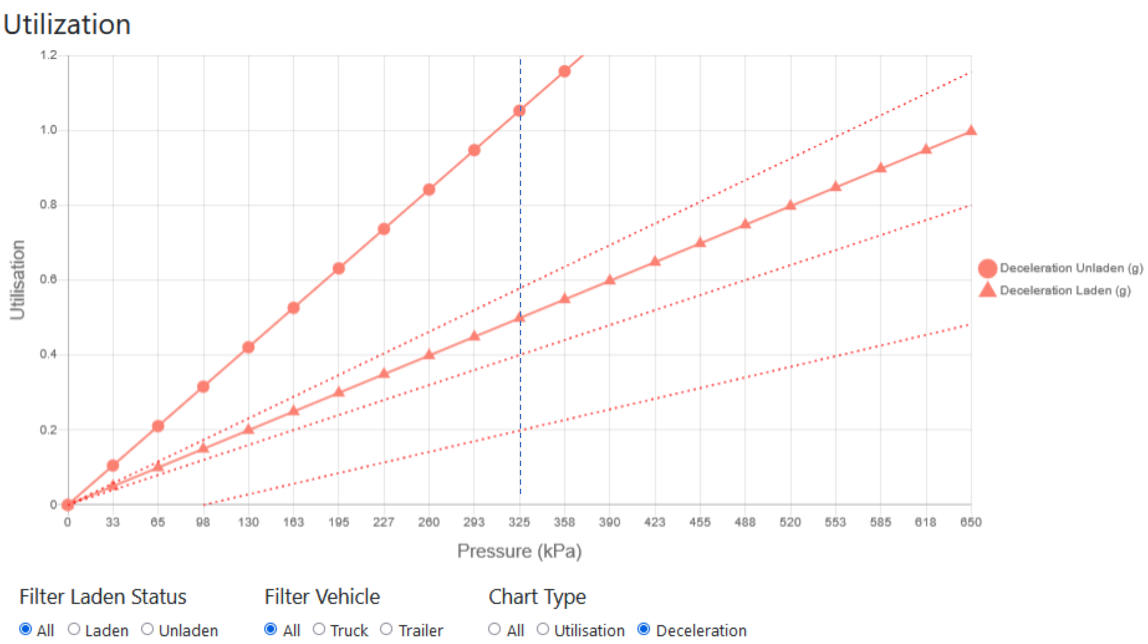


Figure A10 Vehicle decelerations

When the tare weight and load heights are changed to 2m, the deceleration results, as shown in Figure A12, do not change. This is correct because according to Newton's second law the deceleration level is not changed by the load height.

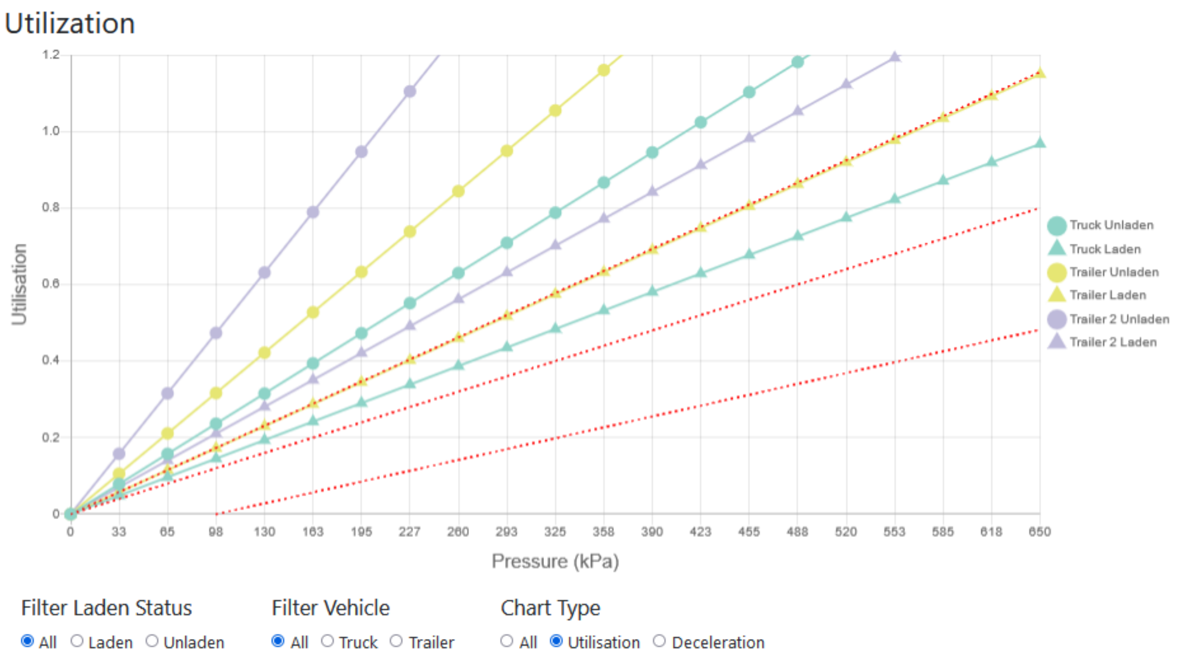


Figure A11 Axle utilisation with no load height

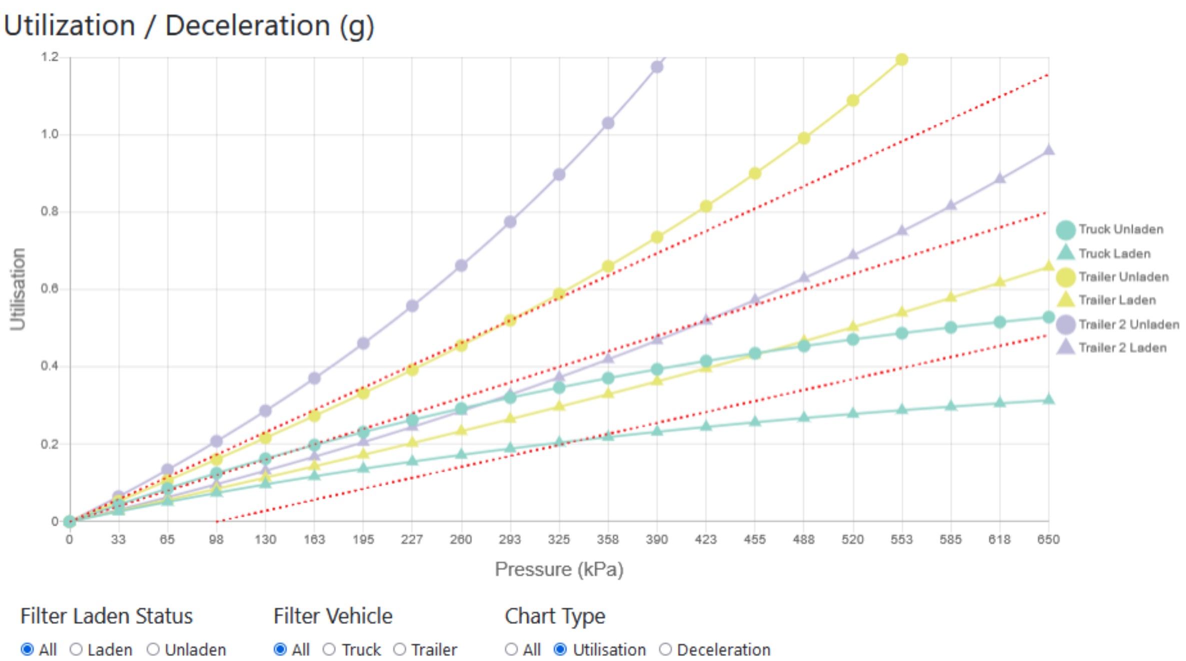


Figure A12 Axle utilisation with load height 2m

In Figure A13 the axle utilisations do not change brake control level because there is no load transfer between axle groups with zero load height.

In Figure A14 the axle utilisations for the front axles curve down because mass transfers forward when the load height is 2m. For the same reason the axle utilisations of the rear axles curve up.

A3.2 With Wheel Lock-up

μ = 0.75 and Wheel Lock-up Factor = 0.7.

Load heights = 0.

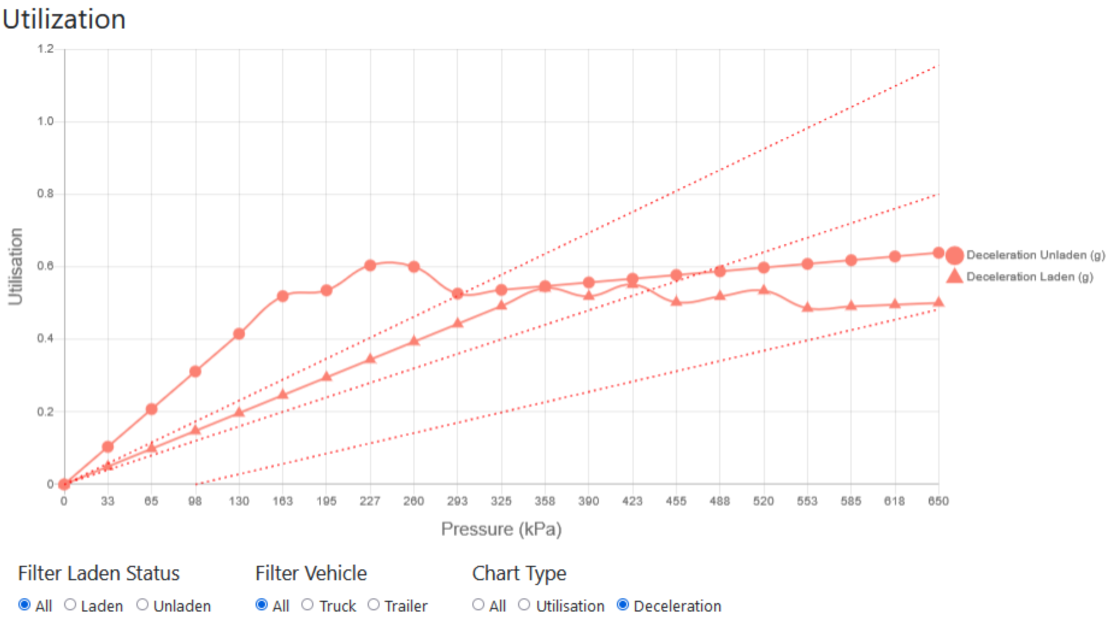


Figure A13 Deceleration

The deceleration is unchanged up to 163kPa (unladen) and 358kPa (laden)

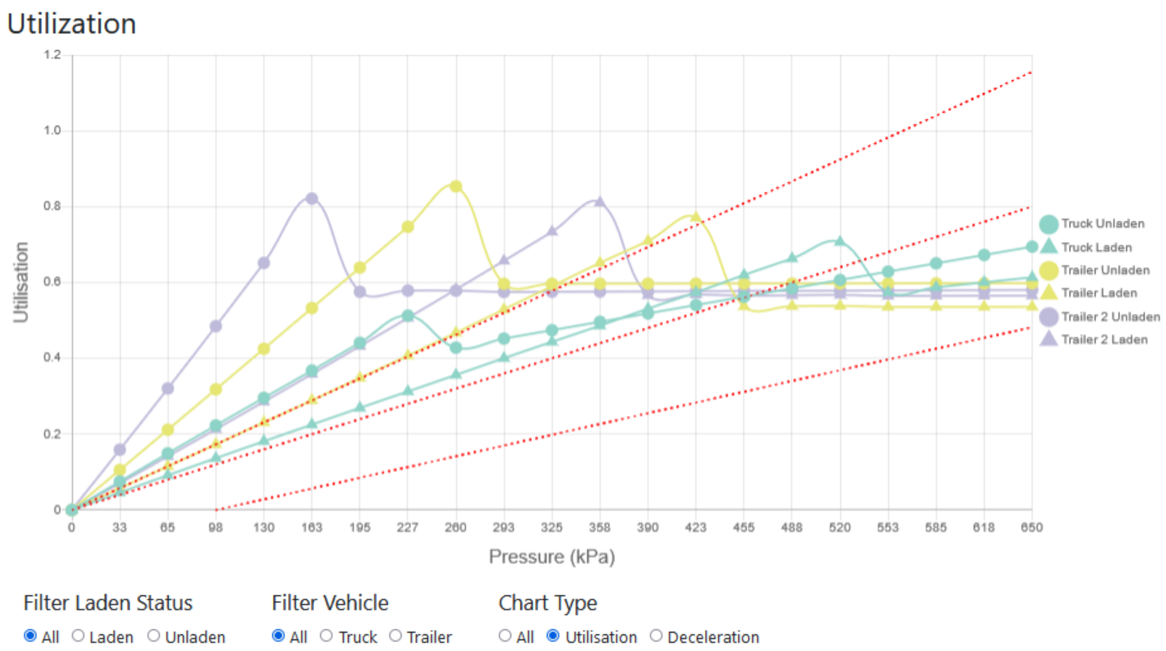


Figure A14 Axle utilisations

These results take account of wheel lock-up. The results on the Summary page for brake control pressures associated with wheel lock-up are not shown. This is done so the User can easily identify when wheel lock-up is occurring on a vehicle.

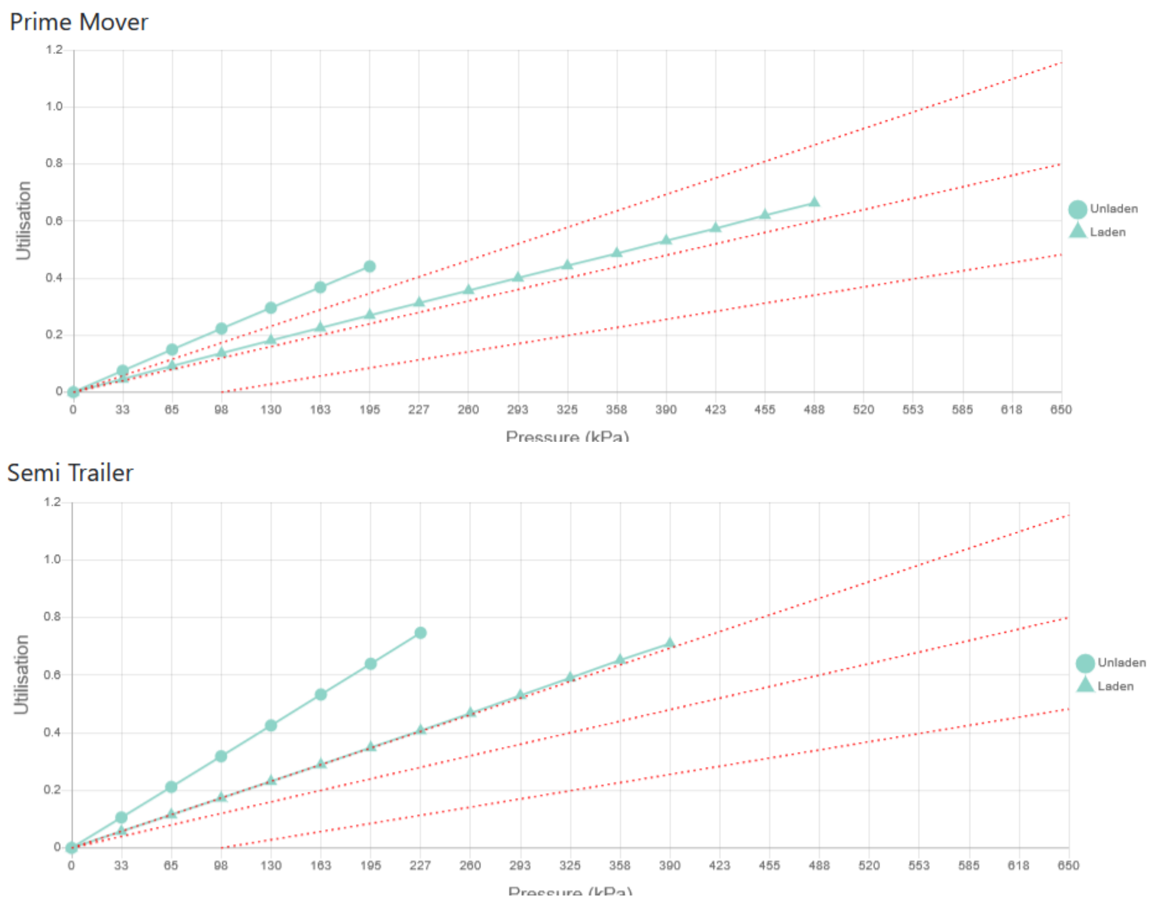


Figure A15

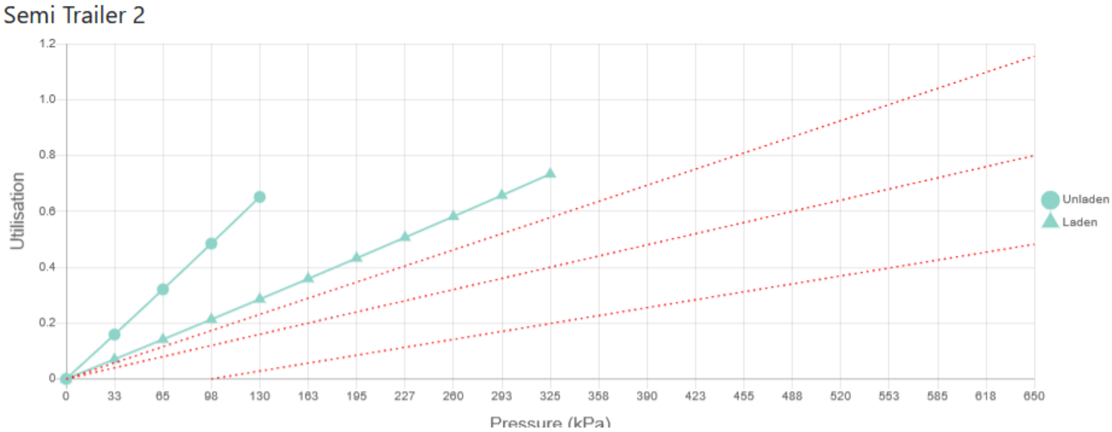

Semi Trailer 2
Utilisation
1.2
1.0
0.8
0.6
0.4
0.2
0
0
33
65
98
130
163
195
227
260
293
325
358
390
423
455
488
520
553
585
618
650
Pressure (kPa)
Unladen
Laden

Figure A16

Prime Mover

Model	Custom Prime Mover
Height of Centre of Mass (m)	0
King Pin Height (m)	0
King Pin Location (m)	3.9
Wheel Base (m)	4
Front Tare Group Weight (t)	4
Rear Tare Group Weight (t)	2
Front Axle Group Count	1
Rear Axle Group Count	2
Pressure Time Delay Until 420kPa (s)	0

Front Brakes

	Brake 1
Model	Custom
Brake Type	Disc Brake
Threshold Pressure (kPa)	0
Axle Torque (kNm)	18.5
Parking Torque (kNm)	18.5

Rear Brakes

	Brake 1, 2
Model	Custom
Brake Type	Disc Brake
Threshold Pressure (kPa)	0
Axle Torque (kNm)	18.5
Parking Torque (kNm)	18.5

Front Tyres

Model	255/70R22.5
Tyre Size (revs/km)	355

Rear Tyres

Model	255/70R22.5
Tyre Size (revs/km)	355

Figure A17

Semi Trailer

Model	Custom Semi Trailer
Height of Centre of Mass (m)	0
Trailer Length (m)	10
Tare Group Weight (t)	4
Unladen Weight (t)	6
Axle Count	3
Pressure Time Delay Until 420kPa (s)	0

Trailer Brakes

	Brake 1, 2, 3
Model	Custom
Brake Type	Disc Brake
Threshold Pressure (kPa)	0
Axle Torque (kNm)	18.5
Parking Torque (kNm)	18.5

Trailer Tyres

Model	255/70R22.5
Tyre Size (revs/km)	355

Trailer Air system

	Air System 1, 2, 3
Model	Perfect IO Characteristics
Brake Type	
Air Ratio at 20% Pressure	1
Air Ratio at 40% Pressure	1
Air Ratio at 60% Pressure	1
Air Ratio at 80% Pressure	1
Air Ratio at 100% Pressure	1

Load

Model	Custom Load
Load Weight (t)	10
Distance From Reference (m)	4
Height from Axle (m)	0

Figure A18

Semi Trailer

Model	Custom Semi Trailer
Height of Centre of Mass (m)	0
Trailer Length (m)	10
Tare Group Weight (t)	4
Unladen Weight (t)	6
Axle Count	3
Pressure Time Delay Until 420kPa (s)	0

Trailer Brakes

	Brake 1, 2, 3
Model	Custom
Brake Type	Disc Brake
Threshold Pressure (kPa)	0
Axle Torque (kNm)	18.5
Parking Torque (kNm)	18.5

Trailer Tyres

Model	255/70R22.5
Tyre Size (revs/km)	355

Trailer Air system

	Air System 1, 2, 3
Model	Perfect IO Characteristics
Brake Type	
Air Ratio at 20% Pressure	1
Air Ratio at 40% Pressure	1
Air Ratio at 60% Pressure	1
Air Ratio at 80% Pressure	1
Air Ratio at 100% Pressure	1

Figure A19