Understanding The Dynamics of Towing

Introduction

This article is designed to give you an insight into what's going on when you are towing a caravan. No matter if it is your first time or you are seasoned veterans, I hope that there will be something here that expands your knowledge and helps you understand what's actually happening when towing.

I won't go into what the maximum weight your vehicle can tow, there are lots of guides available on the Internet for this and how to understand the match between tow vehicle and caravan. There are also guides that tell you what you can legally tow with your driving license.

It was written in response to a number of questions asked on the Caravantalk.co.uk forums.

The Basics

Under acceleration or braking, if the caravan is in line with the vehicle, the forces acting will always be in a straight line, however, if the caravan and towing vehicle are not aligned the forces under breaking conditions will have a different effect.

Caravans have two types of braking systems - “over-run” and electronic. Electronic brakes are more common on continental and American caravans and not often found in the UK. The most common system in the UK is the “over-run” type brakes. There is also a hybrid of this, one of the well-known caravan chassis and hitch manufacturers offer a stability system. This is a device to electronically operate the caravan over-run brakes in the event of the caravan becoming unstable whilst being towed. We will concentrate on the most common type, over-run brakes, but the effects are almost the same no matter what braking system you have.

Caravan “over run” brakes are operated by compressing the coupling against a tension device, once the tension device compressed, the brakes are activated by a system of leavers or cables applying force to the brake shoes in the hubs on the axle, slowing the caravan down. As the caravan slows, the force on the tension device is reduced releasing the breaking force. In a perfectly maintained system, the manufacturer calculates the maximum force required on the breaking system and create a tension device to give the correct forces to enable the most efficient braking and to reduce the “pushing effect” on the towing vehicle to only the force required.
to activate the braking system therefore helping to prevent it from becoming unstable.

However, there are limits, if a caravan is overloaded for example, the tension device may not be able to resist the mass of the caravan pushing into the rear of the towing vehicle and the force acting on the brakes may be more than the designer allowed for and lead to the caravan wheels locking up completely. Tyres also have an effect, if they are badly maintained (under or over inflated, worn tread etc) the grip on the road surface will differ to the manufacturers original calculations and will effect the efficiency of the braking system.

If the caravan is off to one side, under breaking, the force transmitted to the tension device will not be in direct line and therefore have a slight reduced effect. In addition, the force acting on the car will have the effect of trying to “push” the rear of the car in the opposite direction, compounded by a slight reduction in the loss of efficiency of the caravan braking system.

Another effect on braking efficiency is the forces acting in a vertical axis. If the caravan and towing vehicle are correctly matched, the hitch height will be in line on both units. Therefore any forces transmitted during braking will be in line, but we will see shortly why this might not be the best position.

If the caravan is “nose high” this has an effect under braking and the stability of the towing vehicle and caravan. The normal cause of this is the hitch height on the towing vehicle being too high, even with the correct nose weight, this will cause instability problems, especially under braking. As can be seen (below) we have a similar situation to braking with the caravan not being aligned with the towing vehicle. In this case, the forces acting as the caravan “pushes” into the rear of the braking vehicle have the effect of “lifting” the vehicle’s rear end. This is also compounded by the fact that under braking, the vehicles centre of gravity moves forward, transferring weight to the front wheels and off the rear wheels so the rear of the vehicle is already lighter than in a normal towing condition.

Under heavy or emergency braking, there could be enough force acting on the rear of the towing vehicle to reduce the weight on the rear wheels sufficiently to cause the rear wheels to lock and lose nearly all braking effect, if the caravan is also slightly out of alignment with the towing vehicle the combined effect of the lateral pushing of the vehicles rear will reduce further the efficiency of the caravan braking (over run) action increasing the force acting on the vehicle and this will quickly escalate pushing the vehicle further sideways resulting in a “jack-knife”

It is essential therefore we tow with the caravan slightly “nose down” and here’s why.

Under braking, the direction of force acting on the towing vehicle from the caravan will be in a slightly downward direction, increasing the load on the rear wheels of the towing vehicle. We know from above, under heavy or emergency braking that the center of gravity of the towing vehicle moves forward and pitches the nose down increasing the load on the front wheels and reducing the load on the rear wheels. By towing “nose down” when braking, the caravan's acting line of force, resists this and imparts a further
downward acting force onto the rear wheels and effectively increasing the grip on the road surface. This has two advantages: firstly, it will resist any tendency for the rear wheels to lock up as the increased grip will resist the force of the brakes and keep the wheels turning, improving overall brake efficiency of the vehicle. Secondly, if the caravan is out of alignment with the towing vehicle, the increased grip will help resist the lateral force imparted on the rear of the vehicle that wants to push it sideways, therefore reducing the chances of “jack-knifing”.

Understanding a twin axle

There are two basic types of twin axle systems, the first is more complex and is usually found on larger trailers, such as car transporters, builders plant and heavy flat bed trailers that are designed for weights up to the 3500Kg limit.

The second system, is basically two single axles mounted on the same chassis. The suspension is a lever arm with a wheel hub at one end and at the pivot end it can be a torsional tube or a square shaft inside a box with rubber packing providing the suspension.

The most common suspension is shown below. The suspension operates by compressing the rubber packing strip inside the chassis box section (axle) as the pivot arm moves up and down with the wheel hub attached at the end. This is a very simple solution and is light weight in construction, low maintenance and there is very little to go wrong. This suspension system is undamped and one of the upgrades often sought is to add shock absorbers to reduce any oscillation.

This system is fine for single axle outfits, however it does have certain limitations when two of these are combined to create a twin axle caravan or trailer. Lets have a look at the suspension again, with an unbalanced caravan. As the centre of mass is moved this has the effect of increasing the load on one axle and reducing the load on the other, and is the reason why the axle load rating is often reduced when used in twin configuration.

There are a number of factors to consider now.

The tyres fitted to a twin axle will have a load rating, just as tyres fitted to a single axle caravan have, however, we are now distributing the load more on to one axle than the other, so if for example the caravan maximum load is 1600 Kg and in a balanced condition, there will be a 800Kg load on each axle. If the tyres are rated for 500 Kg, this is within limits (remember 800 Kg on an axle means a load of 400Kg per tyre) However, if the caravan is loaded with the centre of mass too far forward, the load on the forward axle now could be 1000Kg and on the rear 600Kg. A 1000Kg load
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on the forward axle is at the maximum for the tyres rated at 500Kg.

The calculation for working out the moment, or centre of mass is quite easy.

Assume the distance between the wheel hubs is 1000 mm and in balance, the centre of mass is 500 mm, directly between the wheels. This will be our datum, so in balance it will equal zero.

So, we can now work out the moments:

It can be seen that by moving the total mass of the caravan forwards by 31.25 mm, the loading on the front axle increases by 50 Kg and on the rear reduces by 50 Kg. Moving the total mass of the caravan forward by 62.5 mm will increase the load on the front axle to 900Kg and reduce the rear to 700Kg.

Now, in practice, we can’t move the total mass of the caravan forward, what we can move is the items we store in the caravan. So, our maximum mass for the caravan is 1600Kg and the Mass in Running Order for the caravan is 1400Kg, so we are allowed 200Kg for the awning, supplies, folding chairs, clothes etc. How will this affect our calculation? Well if we use exactly the same table as above only this time, we calculate for the 200 Kg movable load. The 1400 Kg MIRO weight will not change as we now assume that everything else in the caravan is fixed in position.

It can now be seen that moving the 200Kg load forward by 250 mm has the effect of increasing the load on the front axle to 850Kg and reducing the rear axle load to 750 Kg. Move the load forward by 1000 mm and the load on the front axle is now 1000 Kg and on the rear axle it has dropped to 600 Kg. The front axle is now on our maximum tyre loading of 500Kg!

One additional factor to consider is the brakes on a twin axle caravan. Some brakes only affect one axle, usually the front one. It is important therefore we make sure the load on the front axle is always

<table>
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<tr>
<th>Total Mass (Kg)</th>
<th>Front Axle (Kg)</th>
<th>Centre of Mass (mm)</th>
<th>Rear Axle (Kg)</th>
<th>Front Arm (mm)</th>
<th>Front Moment</th>
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<th>Centre of Mass (mm)</th>
<th>Rear Axle (Kg)</th>
<th>Front Arm (mm)</th>
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higher than the rear one in all conditions of towing. We have to take into account that some pitching (the caravan rocking front and rear) when towing due to undulations in the road, potholes etc, so manufacturers often specify a minimum nose weight (please check with the manufacturer of your caravan for more information) to ensure that even in a pitching motion, there is sufficient load on the braked axle for the brakes to work efficiently as the manufacturer intended.

Nose Weight.
It does not matter if you have a single axle or twin axle caravan, there are four things that need to be checked:-

- The manufacturer of your vehicle will have specified a maximum nose weight that can be applied to any towing hitch installed on the vehicle.
- The manufacturer of the towing hitch will have specified a maximum nose weight that can be applied to the tow bar.
- The manufacturer of the hitch fitted to your caravan will have specified a maximum nose weight that can be applied through the hitch.
- The manufacturer of your caravan will have specified the maximum nose weight that can be applied.

For some vehicles, the recommended nose weight loading will be the same as the tow-bar loading as they are usually manufactured as “OEM” parts for the vehicle manufacturer. Sometimes though, the tow-bar might have been an after market fitting and will carry the relevant EU approval, BUT might have a different nose weight loading to the original equipment fitted tow-bar. It is essential therefore you check both. In most 4 x 4’s (Land Rovers for example) the maximum nose weight can be as high as 150Kg, but most of the popular hitch types the limit is 100Kg. Some caravan manufacturers recommend a maximum nose weight of 80Kg.

It is imperative that you check the limitations of the vehicle, tow-bar, hitch and caravan, before going any further. Write your figures in the following table :-

<table>
<thead>
<tr>
<th>Weight (Kg)</th>
<th>Vehicle Manufacturers Maximum Nose Weight</th>
<th>Tow-bar Manufacturers Maximum Nose Weight</th>
<th>Hitch Manufactures Maximum Nose Weight</th>
<th>Caravan Manufacturers Maximum Nose Weight</th>
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<tr>
<td></td>
<td>150</td>
<td>150</td>
<td>100</td>
<td>85</td>
</tr>
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In the examples, I will use typical figures, these may NOT be suitable for your vehicle and caravan combination! Once you have obtained the four values, you can now work out what is the maximum nose weight limit you can use. Here is an example:

In this case, the maximum nose weight that can be used is 85 Kg. It is always the lowest weight in the table!

With the caravan perfectly loaded and all the weight in the middle, it should balance on its main wheels...
But this is not an ideal situation. The caravan is not stable and the slightest force acting on it will tip it one way or another. To stop this happening, an offset in the centre of gravity is used, simply by

loading the caravan with the weight slightly forward. For single axle caravans, this is already
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done to some extent by the manufacturer when he designs the caravan. It will have been designed with a slightly forward “C of G” or Centre of Gravity.

We can calculate where to put the load inside the caravan to obtain the correct nose weight, but in practice, it is easier to just simply weigh the caravan at the point of the hitch. There are special gauges to do this, but simply using a pair of bathroom scales and a short piece of wood placed between these and the tow-hitch can achieve the same results.

Measuring the nose weight on any caravan or trailer should always be done on level ground.

First, we need to ensure the tow hitch on the caravan is the same height as the tow ball on the towing vehicle to be used. This is achieved by simply adjusting the jockey wheel up or down. Make sure the caravan handbrake is ON!

Next we want to measure the height between the top of the bathroom scales and the underside of the caravan tow hitch.

Measure from the scales to the underside of the hitch. If you intend using a section of broom handle so it fits inside the hitch, don’t forget to allow for this measurement.

Once you have the length, cut a piece of wood 50mm x 50mm section to length. It is now a simple case of standing the piece of wood on to the bathroom scales and slowly lowering the hitch on to it by winding the jockey wheel up. Don’t forget, you MUST chock the wheels first to stop the caravan moving and then release the handbrake BEFORE starting to lower the hitch onto the wood. “Why?” I hear you ask, well, if the handbrake remains on, the pivot point isn’t actually the axle, it is the point where the tyre touches the road surface and with the handbrake on all you will be doing is turning the wheel slightly to let the nose come down, its not actually pivoting and, if you chocked the wheels, it will not roll forward slightly and you will get the correct reading on the scales!

Once the jockey wheel is clear of the ground, you can now simply check the nose weight by reading what is on the bathroom scales. If the reading is higher than you want, lower the jockey wheel, apply the handbrake and adjust the load in the caravan by moving something forward of the axle back a little towards the rear.

Now lets think about that for a moment. What could happen, is to get the correct nose weight, you could have to move a lot of stuff to the rear, in fact too much stuff too far to the rear. What are the effects of this!

When being towed, all caravans have a tendency to sway from side to side, either due to undulations in the road, the effects of cross winds, or more likely the effects of lorries and large vehicles overtaking. If there is a lot of weight at the rear of the caravan and the nose weight is correct, there is a fair chance there is nearly as
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much weight at the front of the caravan too! Having extreme weight at the front and rear is known as the dumbbell effect..... As the two areas of mass are further away from the pivot point, it has a tendency to increase in oscillation rather than be damped by the force of the towing vehicle.

In order to reduce the dumbbell effect, it is essential to keep the mass towards the centre of the pivot point. It may mean just lying the awning on the floor directly above the axle, but in some cases, it might mean removing heavy items from the front locker and stowing them in the caravan or in the boot of the car. Moving any weight from the caravan to the towing vehicle is always a good idea. As a general rule, the heavier the towing vehicle and the lighter the caravan the easier it is to tow.

What nose weight should I use?

There isn’t a simple hard and fast answer to this. Nearly all the motoring organisations, caravanning clubs and towing associations recommend the following advice:

The Nose Weight should be between 5% and 7% of the loaded trailer weight.

Again, with some combinations of caravan and towing vehicle, the maximum nose weight specified by the vehicle could be less than the recommended 5% to 7% (This is usually with a light car and a heavy caravan, but be careful, there are some 4 x 4’s that have a surprisingly low nose weight limit)

As I said at the beginning, I won’t go into what the maximum weight your vehicle can tow, there are lots of guides available on the Internet for this and guides that also tell you what you can legally tow with your driving license.

Can I just load up to the maximum nose weight my car and caravan allow?

Yes you can... but hang on a minute, lets think about this. Remember back at the start we went through some of the forces acting on the towing vehicle. In the braking example, we decided that towing slightly nose down was the best option, and we discovered that under braking forces, the caravan imparted a downward force on the rear of the vehicle, well this will increase the nose weight and if you are loaded to the maximum nose weight permitted for your combination, the act of braking will take your nose weight over this limit. Most of the components are engineered to take more than the specified limits, but to continually exceed this under braking will contribute to increased fatigue on all the components, in addition, the over-run system will be subject to increased lateral forces and may not work as efficiently or as smoothly as the manufacturer intended. So be careful if you are loading close to the nose weight limit.

Other Effects

“Dutch Roll” is a tendency for the caravan to not only pitch forward and backwards, but roll from side to side as well. This is usually most common on motorways where the inside lane has been worn down to two grooves by heavy goods vehicles. What happens is one side of the caravan will settle into a groove and the other side will ride on the edge of the adjacent groove. This will set up a rolling motion in the caravan, and will have the effect of trying to move the hitch from side to side. As the vehicle and caravan travel forward, the undulations will also set up a rocking backwards and forwards motion in the caravan, which has the effect of first lightening the load (nose weight) on the hitch, then increasing it. The combined effect of this is the caravan hitch will move in a circular motion first sideways then down, then sideways in the opposite direction and finally upwards again, repeating continuously. In some vehicles this can be felt more than in others, and sometimes you can have a passenger that
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normally is OK, but when you are towing, might complain of feeling a little travel sick.

Usually, the effects of this can be minimised by changing your speed slightly. You might also notice a similar effect as a large vehicle overtakes you, it first draws you towards it as the flow of air round you and the vehicle cause a pressure drop between the vehicles, then a push away as the airflow changes and the new flow creates a pressure wave between the two vehicles.

Wind Loading and Nose Weight

One effect that is sometimes not considered is the effect of actually driving on the nose weight of the caravan. Any tow vehicle, no matter how aerodynamic, is when towing actually towing the equivalent to a house brick aerodynamically.

There are some things that can be done to reduce the aerodynamic drag by the caravan designers when towing. The closer the caravan is to the rear of the car (sometimes called “short coupled”) reduces the turbulence created between the car and caravan as the car moves through the air. This is why sometimes you see articulated tractor units fitted with fiberglass infill pieces behind the cab to reduce the gap between the rear of the cab and the front of the trailer. For most caravans, there is little we can do, but we need to consider the effects on the caravan.

We are in effect, towing a flat wall into the wind, the effect this has on the caravan is to try and pitch it backwards on its axle, which as we know from working out the nose weight, moves the effective centre of gravity rearwards and as a consequence, will reduce the nose weight on the hitch.

Drag increases with speed, in fact drag is proportional to the square of speed \((R \propto v^2)\) so, in simple terms, if you are doing 30 Mph and and accelerate to 60 Mph, the drag at 60 Mph will be four times the drag than it was at 30 Mph. That means you will have to have four times the power from your engine to maintain 60 Mph than you did at 30 Mph. What does this mean for nose weight? Well in basic terms, at 60Mph there will be 4 times the force trying to tip the caravan backwards. Its not quite that cut and dried though. As the force of the wind on the front of the caravan tries to tip it backwards (red arrows below), it is stopped by the hitch, it can’t move up because its attached to the towing vehicle, therefore, the force is translated into two elements, one trying to move the hitch upwards reducing the nose weight, the second is converted into a force pushing down on the axle (yellow arrow below).

Its not quite simple enough to calculate these forces and effects. The effects are known by caravan designers and they try to mitigate some of these by designing the caravan to be as aerodynamic as possible and reduce the turbulent air at the rear of the caravan as much as possible. Again, they have to consider what will be towing the caravan, everything from saloon and estate cars up to big 4 x 4’s. They all will have a different effect on the air flow over and around the caravan.
Effects of Inclines.

The effect of an incline also has an effect on towing. If you park your caravan across an incline, and unhitch the car, if you were then to take the handbrake off, the caravan will turn, so its hitch (assuming that the nose weight is correct) to point down hill... shortly before rolling off into the sunset! Let's have a look why.

The centre of gravity on an incline is angled directly downwards when looking from the front, and if viewed from above slightly off to one side in the direction of the downwards slope. If you were to take the handbrake off, as the centre of gravity is in front of the axle (it has to be because of the nose weight) there will always be a tendency for the hitch to move down the slope.

Now, if you are towing across the incline, the caravan will always want to push the rear of the car in the direction of the down hill slope. Farmers driving tractors are very aware of this and when they are towing farm machinery and traversing a slope, especially a wet grassy one, they always take extra care. It is highly unlikely that you will encounter an extreme slope, but to know about the effects beforehand is always a safety bonus. Remember earlier we looked at Dutch Roll... well this is one of the factors that can contribute to it. If you have one wheel in a “rut” caused by HGV's and the caravan's other wheel is not quite in the other rut, all things being equal, the caravan hitch will push ever so slightly in one direction, this can most often be felt as the caravan “hunts” from one rut to another, i.e. one wheel running in the rut, then moving over slightly and the other wheel then running in the rut. This has the effect of the hitch pushing the rear of the car from side to side as it transfers from one rut to another. A similar sensation can sometimes be felt on some trains.