GETTING TO GRIPS WITH TYRES

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THE BUDDHIST WHEEL OF DHARMA

The Hub: The Discipline needed to steady and stabilise the Mind
The Spokes: The Wisdom needed to defeat Ignorance
The Rim: The Concentration needed to embrace the Learning

Two Wheels: Need double Discipline, double Wisdom and double Concentration
(T.G. White, *Popular Philosophy for Motorcyclists*, yet to be written)

CONTENTS

FOREWORD

JUST A DREAM

Wonderful! The confusion of the Channel port was behind them. Ahead stretched an empty highway, shimmering in the morning heat. Gone were the twisty, bad roads, dense traffic, tractors mixing with trucks, the Irish rain – and gone were niggling speed limits. Well, not completely, but a 130 kph limit was as good as no limit, particularly when *everyone* said that French police turn a blind eye to anything below 150 kph or so. The southern sun, a holiday dreamed about and planned for so long was just a throttle twist away. He twisted the throttle.

It had been a rough ride to get so far. Of course he had bikes as a lad. On those two-stroke screamers he had often ridden on the wild side but meeting and marrying Mary had brought him back into the fold. A man with a growing family had responsibilities. Being a good man he had faced up to those. He'd worked hard and long, but now the little house was secure, the children had been educated and were running their own lives. So, some shared dreams had been fulfilled. It was time to fulfil some more – such as time with just the two of them close together; holidays in the sun; a return to motorcycling … and … and. Hey! What about the first three all at one time?

Well, not quite all these were shared, because Mary had not been part of that earlier riding life. Nonetheless, having been at his side and trusting him for so long since, she was willing to go along with this recurring dream of his – under one condition! Having struggled for them so long, she didn't want to relinquish *all* home comforts – even for a dream. So, the touring bike had to be big and comfortable, able to carry those little extras. She found the Honda GL1500 ideal.

Although not quite the Ducati of his dreams, he could live with the 1500 and its 397 kg kerb weight. Ridden hard it could match many a sports bike. True, it didn't have the luggage volume of their car but, for a motorcycle, its capacity was the best around. Indeed, although his and Mary's riding weights added up to 165 kg, the bike could swallow much more than the maximally allowable load capacity of 178 kg would suggest. Then, with a 6000 km service interval, it didn't need much attention – certainly none for the planned 3000 km holiday. After all, he had put it in for a service in Spring, 2000 km before. So, with every nook and cranny loaded with those necessities and little comforts, they faced that French highway with smiles of anticipation.

150 kph, eh? Let's see! He had ridden that speed before. Often he had even surpassed the magical Ton on a Kwacker H1 – the infamous 'Widowmaker'. However, that was only for odd moments on those rough rural roads – never over long stretches, as he was doing so easily on that 1500. There weren't many long stretches in Ireland then! Yes, thirty years before he'd been there … *and* he had come back to tell the tale – even about how he had got used to the feeling of a Kwacker frame getting out of shape. But a 1500 doesn't get out of shape, does it? What everyone claimed was true – it did run as if on rails. Yet when, after riding that fast foreign highway for nearly an hour, the back end momentarily felt a little squirrelly he was not perturbed. Road surface, maybe. A few seconds later, his shock as the back tyre loudly exploded at 152 kph did not last long. The bike snaked, the rim dug into the tarmac, and it cartwheeled into the roadside barrier. Mary lay motionless with several broken bones. He was dead before the wreckage of the bike came to rest.

(Based on a true event in early summer, 2002. The accident analysis concluded that probably the initial rear tyre cold pressure had been no more than that recommended for moderate speed solo riding. The total loading greatly exceeded the maximal gross vehicle weight established by the manufacturer. Consequently, the rear tyre overheated so much that the rubber compound and carcass construction broke down. It disintegrated … instantly … explosively. The only surprise was that the lady passenger survived … to become a widow, with no dreams – only nightmares.)

1. INTRODUCTION

> The tyres are the most significant part of the whole machine. The rest of the bike should be designed around whatever is the best set of tyres for the job. … Choosing tyres is never easy. … Other people's tests and magazine tests are a useful guide, but beware of taking too much notice of … (what they say).
>
> John Robinson, (Motorcycle Tuning: Chassis, 2nd edn., 1994, p. 33.)

Motorcyclists spend a great deal of time 'kicking tyres'. At rallies, cafés, pubs and other meeting places, they argue the pros and cons of certain tuning modifications, of one lubricant against another, of this or that after-market accessory, etc. They also kick tyres about … tyres. Some swear by Michlops, others by Duntinentals. One group would never mount Metzellis while Bridgelins are the only choice of a few. However, the debaters are usually starting from different places on the grid of expectations – and so talk at cross-purposes. Some base their opinions on a need for 'grip', others for long wear. There are riders who would forgive much in a tyre if only it felt safe in the wet – and so on. Some are unreasonably prejudiced against the choices of others but, as we all know, prejudice is based on restricted knowledge and understanding. A motorcycle (m/c) tyre can't be judged solely on this or that aspect. Its overall performance is made up of many factors. No tyre can perform maximally in all of them – because some are brought to the fore at the inevitable cost of others. This makes the choice of a tyre, like much in Life, a compromise. It is determined by the demands of the individual machine, by the way it is ridden and by the personal expectations of the rider.

Riders' mouths may be filled with large doughnuts of black rubber but for all the chat they rarely talk about the most important issue. They may get their knees down on the road but they rarely get their minds down to the nitty-gritty. That is the place where it is really nitty-gritty – those two small patches where just part of a tyre meets the road, where the drama of a ride is played out on the tarmac stage. An engine, a suspension – even the rider – may provide the script for a fascinating play. However, the plot they create can only reach that stage through those few square centimetres of contact patches. Usually forgotten, sometimes abused, the tyres and their function, quality and character at those contact patches always have the final word in this theatre.

Theatre? Maybe not, because here it is real life – the real life-and-death part of m/cycling. That script may generate myriad forces from acceleration, braking, turning, road holding, stability, etc. Yet they *all* come together where the tyres meet the road – not as a grand finale but from the moment the curtain goes up on the ride to the moment it ends with smiles or tears. *That* is when heroes[1] can be identified and the bodies left on the stage counted. So, with them being crucial in determining the winners and losers, it is surprising that some riders pay so little attention to their tyres. Some throw away original exhausts *specifically* designed for their machine and replace them with generally designed after-market items – imagining that an occasional slight increase in

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[1] *Hero*: a skilled motorcyclist who never creates or gets into a dangerous situation and arrives home with no 'heroic' stories to tell. T.G. White, *Popular Philosophy for Motorcyclists*, yet to be written.

peak power and the usual great increase in noise are not at the cost of mid-range power and legality. More money may go on replacement suspension units, yet correct, properly cared-for tyres may contribute more to good handling. Even bigger money may go into engine tuning to 'improve' a 125 hp, 250+ kph (160+ mph) m/c to one capable of 300+ kph (190+ mph). Yet by abusing their tyres, such back-yard tuners may lose out by not being able to put down on the road the power they already have.[2]

So, although the opening quotation from John Robinson is so true for the *choice* of tyres, that choice is only part of the story. The *use* of tyres is crucial as well. It is no good starting off with a good tyre if it is not used and maintained properly – used and maintained within its design parameters. The tragic story related in the Foreword illustrates this only too bitterly.

Tyres are not just round tubes of rubber holding air[3] – to be chosen, mounted and forgotten. They are major players, technically very sophisticated designs, contributing more to a ride and its safety than any other part of the plot – except the rider him/herself. Because its internals are working every moment an engine is running, few riders would forget the need for lubrication, adjustment and care. Yet a tyre is working during every inch of movement. Vaguely aware of the demands made on tyres but out of touch with the great technical advances in recent years, I thought it high time to brush up on what tyres are, what they do and how they do it. I didn't want to be one of those riders expressing forthright opinions on subjects they know nothing about.

For background, Tom French's not so recent (1989) book, *Tyre Technology*, was the only one I had devoted to the subject alone. Although dealing primarily with car tyres, it also covers scientific and technical aspects applicable to m/c tyres. Many books on riding skills, m/c tuning and design contain chapters on tyres – as indeed they should to be complete. (I will add a short list at the end.) Then, I have collected a few articles from m/c magazines, though their content is often superficial. Finally I explored some tyre manufacturers' Internet web-sites.

One aim of my searches was to be able to give some halfway intelligent answers when asked by riders – riders who don't or can't accept that m/c manufacturers recommend the optimal tyres for their machine –

"*What are the best tyres for my m/c?*"

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[2] Dave Minton recently wondered about this thirst for engine power – and its imagined benefits – as against a search for better handling (Classic Bike Guide, p. 33, Jan, 2003). He imagined tweaking a 1911 Norton rolling chassis with a Honda CBR600 engine – expecting to get an unmitigated riding nightmare. Another imaginary 'tune' put a 1925 549 cc Triumph SD engine into a late 1980s Honda CB250S rolling chassis. Considering the power needed to get around in today's riding world, he saw this 'Trinda' as a potentially viable 'marriage'. In other words (Dave Minton's), engines, and absolute power, play a minor role. In my words, handling – due to the chassis but mainly due to the tyres – plays the major role.

[3] "A pneumatic tyre is a flexible, toroidal, compressed gas (normally air) container mechanically attached to the outer circumference or rim of a vehicle wheel. The name is derived from 'attire' – a protective covering, or coat: in this sense the American spelling 'tire' is closer to the original than the British 'tyre' … (a tyre is still called a 'cover' in the rubber industry)" *T. French, 1989, p.1.* So now you know!

For those needing a halfway intelligent answer now – without interest in the 'whys' and 'wherefores' – my instant, pre-emptive response is:

"THERE ARE *NO* BEST TYRES FOR *YOUR* M/C!"

> "There might be some bad ones, but no best ones. The best must, first of all, suit your m/c. Second, they must suit your physical riding style. Third, they must suit your psychological demands or the 'feel' you want and/or need. Fourth, they must suit the climate where you mainly ride. Fifth, they must suit the road surfaces you commonly encounter. Sixthly (and this is the most trivial aspect), they must suit your pocket. The chances of identifying your supposedly best tyres – the ones that satisfy these criteria – in a dealer's store-room or a mail-order tyre catalogue are remote. Unless your riding friends match you on all these factors, then their recommendations are limited. Lastly, having identified and fitted the best possible tyres, they will be the worst ones if they are not cared for properly."

Needless to say, I didn't come to this view instantly. The process of discovering the 'whys' and 'wherefores' is documented in the following less than instant text.

2. THE EARLY HISTORY OF TYRES

It would be surprising if the name of Robert William Thomson was familiar. After all, he suffered the fate of many brilliant English inventors – to be forgotten and then to have his ideas developed at great profit by someone else. Already in 1845 Thomson invented and patented the first pneumatic tyre. True, it was made of a circular tube of air-filled leather but it did survive 1200 miles of the then unmade English roads when mounted on a horse-drawn carriage. (Today there are riders of certain sports m/cs who would not sneer at such longevity with their modern rubber 'boots'.) Thomson even published the results of controlled scientific experiments conducted in the Spring of 1847, in Regents Park with a horse-carriage weighing 534 kg. (At that weight he could have used a modern Gold Wing m/c!) He compared the draught (resistance to motion) of the carriage with the then normal iron-hooped wheels and then with his patented, pneumatic wheels – his 'Arial Wheels'. On smooth macadamised road he found a saving of 60%. On a new stretch of broken flints the saving was an enormous 310%. Thomson also developed a solid rubber tyre and this became popular as his pneumatic version – invented before its time – fell into oblivion.

The time for the pneumatic tyre came 40 years later when an Irishman, working in apparent ignorance of Thomson's patents, developed and patented the first rubber-based pneumatic tyre as we know it today. That was the veterinary surgeon, John Boyd Dunlop. He wanted to make the ride of his son's tricycle easier and more comfortable over the rough streets of Belfast. (Some things don't change!) Dunlop had the same theoretical approach as Thomson before – with "*the tyre acting as a circumferential spring around the periphery of the wheel with the dual objective of reducing resistance to motion over uneven road surfaces, and of lessening shock and fatigue-creating vibrations arriving from them.*" (French, 1989, p.1.)

The time for the invention had come because the upper classes of Britain and Europe discovered the joys of bicycling on John Starley's the newly developed 'safety bicycle' (like today's machines and not the penny-farthing of before). The practical benefits of this invention and that of comfort using these new-fangled bicycle tyres gave the fashion an enormous impulse. Those advantages were captured in one of Dunlop's 1889 advertising blurbs. Some other far-reaching consequences were also noted:

> "The advantages which accrue … cannot be fully understood except by a personal trial. Vibration, with the consequent nervous exhaustion, which tells against a rider … even more than physical fatigue, is practically eliminated. All vibration is intercepted between the rim and the ground and consequently the frame of the machine receives no jar, and will last much longer than the frame of a machine fitted with solid tyres. As a result …riders will be able to use lighter frames, with a corresponding increase in speed and ease of propulsion. (These factors) … will, it is believed, place the pneumatic tyred machine beyond the reach of competition."

Beyond the reach of competition? Well, with sportsmen always on the look out for patent recipes for success, already in that year of 1889 bicycle races were being won on pneumatic tyres. In next to no time tyres were industrially produced widely and there were vast sales to those rapidly growing leisure and sporting classes of Victorians.

Although the humble bicycle gave rise to the birth of pneumatic tyres, another development was waiting in the wings – the automobile. Using the know-how from their rubber and bicycle tyre business, two French brothers, André and Edouard Michelin, fitted pneumatic tyres to an automobile for the 1895 Paris-Bordeaux race. The relentless progress of the automobile, also driven by the needs of war 20 years later, then led to the emergence of the rubber-based pneumatic tyre as a central element in modern transport.[4]

But have demands and expectations in respect to tyres changed in a century of progress? Table 1 is from one of the 'bibles' of information, the 5th edition (2002) of the Bosch '*Automotive Handbook*' published by the U.S. Society of Automotive Engineers (SAE).

TABLE 1: PERFORMANCE CRITERIA FOR AUTOMOTIVE TYRES		
No.	MAIN CRITERIA	SUB-CRITERIA
1	Ride Comfort	Soft suspension, low noise, smooth running (low out-of-roundness)
2	Steering Behaviour	Steering effort, steering precision*
3	Driving Stability	Straight-ahead stability, cornering stability*
4	Driving Safety	Tyre stability on rim, tyre/road adhesion*
5	Durability	Structural stability, hi-speed performance, bursting pressure, puncture resistance
6	Economy	Service life (mileage), wear pattern, sidewall wear, rolling resistance, re-treadability
* most important for winter conditions		

The first three criteria do seem more or less to express the original aims – bearing in mind that these are criteria for automobile tyres. Personally, although 'ride comfort' is important for touring m/cs, many riders would first seek 4, 3 and 2 from a m/c tyre – grip, stability and steering precision. The Handbook itself notes that Criteria 5 and 6 have moved up the scale of priorities in respect to commercial operations (long-distance trucking, high-speed, transcontinental bus services). Here, there are expectations of durability for 200'000 km (120'000 miles). Further, today's fuel prices obviously play a major role in economic operation, so anything that reduces fuel consumption – such as lower rolling resistance – is important. Tom French gives an example for medium-sized trucks (p. 129-130). A variety of processes contribute to the energy-loss when a tyre is rolling – tread compression (32% of the loss), tread flexing (27%), rubber-compound elasticity (12%), tyre-cord stresses (29%). So, anything that reduces these – reduces the amount of rubber, the number or length of cords, the flexibility of the whole construction – will reduce the energy losses and improve vehicle economy.

[4] When automobiles were first developed, carriages, carts, wagons etc. usually ran on wooden or iron-rimmed wheels, as did public stagecoaches. Other public transport, such as trains and horse-drawn trams, had solid steel wheels on steel tracks. In this context, Tom French touches upon an interesting thought. If the pneumatic tyres developed for two-wheelers had not been available – to provide comfort, a (relative) lack of vibration and freedom from the fixed (and expensive to lay) routes of tracks – would the automobile have been accepted, have caught the public imagination and economy in the way it did?

This illustrates that for particular needs a tyre is not just a tyre.[5] Its construction plays a role. (Tyre construction will be discussed in more detail later.) For example, laboratory studies showed that the rolling resistance of a cross-ply tyre for a 13-ton diesel truck was about 9 kg per ton (19.9 lb/ton) of vehicle weight. Radial tyres for the same vehicle had a rolling resistance of about 5.4 kg/ton (11.9 lb/ton) – 60% of the cross-ply value. These were tested on a road route in a controlled experiment. Radial tyres gave the truck a 13.6% better fuel economy. On a touring m/c I certainly would prefer to worry about the next fuel station after 275 km (172 miles) instead of 240 km (150 miles). Perhaps the right choice and care of my tyres will promote that preference.

[5] Well, I always thought this was universally true until I was in Myanmar (Burma) recently. Outside a village (… er! …) 'workshop' a grease and grime covered lad was repairing yet another puncture in a truck inner tube. (It already had more patches than designer jeans.) Through an interpreter I wondered what on earth he was going to do with that rag bag of rubber. A broad smile (they come readily to the lovely Burmese people), a few words and a gesture explained. It was going into the tyre behind me. I followed the gesture – and became even more puzzled. The said 'tyre', its tread and side walls, had been planed absolutely smooth. It glistened in the tropical sun like a shiny doughnut of liquorice. My interpreter passed on my confusion and disbelief that this … this … object would ever be used on the road. I got immediate assurance that it would not be – it had been planed to fit into an even bigger, nearby tyre that was in better condition. At least this was obvious to me – because the cords of the second tyre were showing through only in a couple of places. "Makes everything much stronger, Sir." This was another assertion I could not doubt, now realising that the only function of a Burmese truck tyre is to hold some air and to stay on the rim. Forget Table 1! Other countries, other customs, other priorities.

3. THE DEVELOPMENT OF TYRES

A feature of the early powered vehicle industry was the manner in which it developed. In one way there were very few vehicle *manufacturers*. Many of the famous marques that we know today started life as vehicle *assemblers*. Parts – engines, carburettors, electrical systems, etc. – were bought in from independent companies for assembly. The assembler may have modified some parts, but development lay in the hands of the sub-contractors. So, there arose a whole secondary industry with such names as JAP, Villiers, Amal, Lucas, Bosch – and later Keihin, Mikuni, del'Orto, Showa, Ohlin, etc. Obviously, tyre manufacturers belonged to this category.[6]

For about 40 years, whatever development there was rested with these and not the vehicle manufacturers. Compared with the second half-century of their existence, the development of tyres in the first half was minimal. (Today, vehicle manufacturers are the driving force for development.) Although the early tyres were very unreliable – wearing out quickly, being subject to frequent punctures – they prevailed because their benefits still outweighed these disadvantages. There were improvements in reliability and resistance to blowout, etc. Improvements in wear properties also followed a greater understanding of rubber science and manufacturing processes. However, there seems little evidence of an interest beyond the original ones – comfort and reduction of rolling resistance.

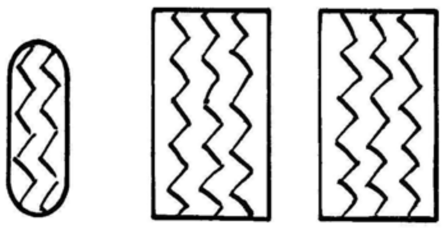
Take today's important property of traction, of 'grip'. Maybe it wasn't a relevant research topic because the grip available with the tyres of that time was still way better than that of wooden or iron-shod wheels. Perhaps the same can be said of tyre tread. Both the needs for ever-increasing traction and to retain it in the wet did not arise because the performance of vehicles was modest. It was only in the 1930s that tyre performance was seen to be a limiting factor. Research started in earnest then, particularly for military aircraft. Today, though, the integral part of tyres in the functioning of vehicles is recognised. They are the subject of design-optimalisation as much as any other part of the vehicle. It is the recognition of this that justifies the quotation by John Robinson given in the Introduction.

Although tyres on all vehicles perform similar basic purposes, the special demands made in one application require such special constructions as to make the tyres almost different animals. Certainly there are vast design differences between the tyres for a child's bicycle and a 100 ton earth-moving machine. It is more difficult to see the immediate difference, though, between car and m/c tyres. Yes, the m/c tyre has a rounded cross-section to help it bank around curves – but other differences seem hard to discern. Tom French indicates the sort of differences in demands that *must* be met with different constructions. Some data relating to different demands are given in Figure 1.

The 1986 Jaguar, with its 264 hp, has 2-3 times the power of the old sports m/c (assuming that you think a 1978 CBX 1000Z to be a sports m/c!). With its 2-wheel drive it also has an enormous area of rubber to transfer this power to the road. Proportionally, though, the m/c puts double the power on to each square centimetre of

[6] Recent developments have seen a m/c company, Bridgestone, change to become a tyre manufacturer.

FIGURE 1: PERFORMANCE DEMANDS ON CAR AND MOTORCYCLE REAR TYRES



	SPORTS MOTORCYCLE	JAGUAR V12 CAR
Power (bhp)	**105**	**264**
Tyre Contact Patch Area (sq. cm)	**102**	**504** (2 x 252)
Power:Contact Patch Area Ratio (bhp/sq.cm)	**1.03**	**0.52**
Weight (kg)	**247**	**1672**
Power:Weight Ratio (bhp/tonne)	**425**	**158**

rubber. This requires particular properties of the rubber molecules and particular types of construction in the tyre-tread. While the m/c tyres need to support the weight of ¼ tonne, the V12's tyres have to support 6-7 times that with their side walls. However, m/c tyre side walls have to sustain more lateral stresses because the m/c rolls around its tyres during cornering. These are additional factors leading to further design differences. These factors of power and weight are best captured together by the power to weight ratios (PWR) of the two vehicles. The CBX 1000Z has nearly 3 times the PWR of the Jaguar. This exposes the tyre to great extremes of acceleration and braking – and performance in this area has to be built into the tyre – to make it as safe and durable as possible.

Dissection of a very recent report (in the German *Das Motorrad* magazine, 26/2002) gives a further illustration of the stresses put on tyres. Three sport-tourer bikes were tested back to back. Maximum power ranged from 72-88 kW (98-120 PS). All were running on a 120/70 ZR17 tyre. At the rear two had a 180/55 ZR17, the other a 170/60 ZR17. Acceleration times from 0-100 kph (0-62.2 mph) ranged from 3.0-3.4 sec. *That* is quite a transfer of drive power through the rear contact patch. However, braking performance was more interesting. Using racing brake techniques (front brake only, because the weight transfer during any slowing loads up the front end to almost 100%), the bikes could be brought to a stop from that 100 kph in 40.2-43.4 metres – in other words, in 2.9-3.1 seconds. So, the contact patch of relatively skinny front tyre is transferring (in a negative sense) slightly more power to the road than the rear. This shows the prime importance of having a good front tyre. (Although for convenience in the text I usually refer to the contact patches of the 'tyres, it must be remembered that acceleration acts over the rear tyre and braking mostly over the front tyre.)

Of course, there were many developments in materials and manufacturing techniques that paralleled developments in vehicle performance – such as synthetic rubbers and fibres, for instance, which replaced natural products. However, this is not an essay on tyre manufacturing. Therefore, such advances will be mentioned only when pertinent.

Such a pertinent advance was in wheel construction. Although some early cars had solid wheels they, like the typical spoked wheels of m/cs, were also far from airtight. So, starting with Dunlop and continuing for 60 years, a rubber inner tube to hold the air was needed. This was less than optimal. It cost money, added weight, added to service costs and was subject to its own failures. These latter limitations were not just restricted to puncture and blow-out risks. It needs no great imagination to see that the inner-tube, no matter how hard inflated, moves independently of the outer casing. This causes wear and, more importantly, it generates heat.

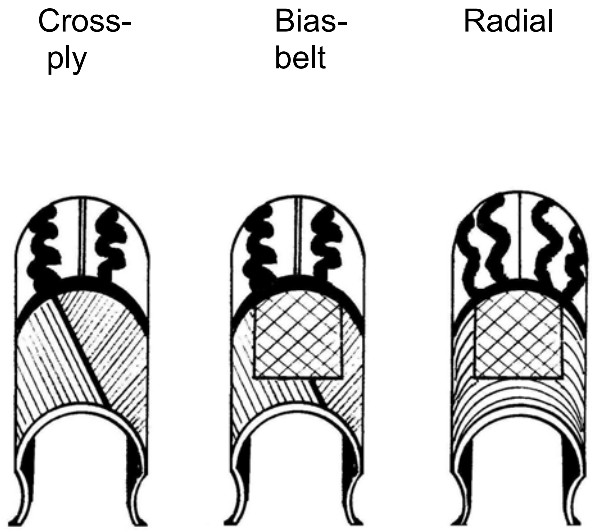
So, pioneered by the Goodrich and Dunlop companies and building on advances in metallurgy and manufacturing processes, wheels for tubeless tyres were developed after WWII. These developments in air-tight wheel-rims obviously had to go hand in hand with developments in tyre construction. The bead of the tyre had to fit and seal with the rim – and to stay sealed in all normal and emergency uses. Also the new rim had to be so formed to prevent the bead collapsing into it should air be lost, with the chance of the tyre being flung off the wheel. Such rims were heavier than their 'tubed' predecessors, but part of this disadvantage was recovered by the lack of inner tube. Further weight recovery was made as lighter materials came into use.

With no inner-tube to hold the air, the tyre itself had to be made air-tight. Contrary to naïve expectation, air seeps slowly through rubber. (Just look at the balloons the morning after the party! It wouldn't be much use if the tyres of your escape vehicle were in the same state when the hostess's husband returned home unexpectedly.) Therefore, impervious inner coatings for the tubeless tyre had to be developed and manufacturing processes developed.

After dealing with some limitations of tyres with the elimination of the inner-tube, attention turned to improving the basic construction of the tyre itself. Classical cross-ply constructions (Figure 2), with the plies/cords running diagonally across the circumference at angles of 45°-70°, no longer met the demands of modern vehicles.

To support the vehicle load and deal with steering forces, tyre side walls need certain properties. With the addition need to transmit tractive force, the same can be said of the tread area. Complicating matters is the fact that the behaviour of the

FIGURE 2: CONSTRUCTION OF TYRES



walls and tread interact with each other. However, if the right combination of properties can be obtained using less rubber and/or fewer plies, additional advantages accrue. Less material means less energy absorption. That means less unwanted heat is generated. Less material also means a lighter weight. Because the tyre is part of the unsprung weight, lighter wheels and tyres improve suspension and steering response.[7]

One advance was the bias-belted tyre (Fig. 2). It was found that the number of plies could be reduced and the tyre performance not only maintained but improved by laying a strong belt around the circumference of the tyre, beneath the tread. This belt can be made of aramide or rayon synthetic fibre or even fine steel mesh. Metzeler have been one of the major producers of such tyres for m/cs. Metzeler claims that particular combinations of ply- and belt material and the angles at which they are laid down changes the ranges of properties of a tyre. These include stability, grip, comfort and durability. So, one tyre would emphasise stability and grip for sport m/cs and another would provide more wear and comfort for touring m/cs.

A tyre engineer from Michelin referred to a further advance in tyres when he was quoted as saying that the only purpose of today's side wall is to join the tread to the wheel – and to carry the moulded imprint 'Michelin'! Such a view resulted from the realisation that a side wall did not need to be particularly high to fulfil its main functions. Indeed, rubber in excess of these functional needs only flexed and generated excess heat. Therefore tyres with a low aspect ratio were developed, where the height of the side wall relative to the width of the tread became less and less. (This height:width ratio, as a %, is part of the full tyre specification.) Although car tyre may have an aspect ratio as low as 30%, it is uncommon to find m/c tyres with ratios of less than 55%. However, again showing the 'swings and roundabouts' of the compromises involved, the new low-profile tyres absorbed vibration and shocks less well. The tyres were noisier and gave a 'harsher' ride. This drove the development of materials and structures further to counteract this.

Michelin was the prime mover in another development – that of the radial tyre. It is so called because the carcass plies follow the radius from one bead, over the top of the tyre and, still running radially, meet the other bead. The ply is at 90° to the rolling direction. With an eye on Fig. 2, compare the cross-ply construction with that of the radial tyre. It is obvious that a cord running diagonally from one bead to the other is longer than one that makes the more direct radial connection. With shorter plies to move and deform – plies that do not criss-cross one another, plies that do not rub against each other as the tyre moves – there is less heat generated. This can be turned around to have no greater heat production in a radial tyre using less material in its construction than in a cross-ply. The radial tyre will be lighter in weight.

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[7] This was recently illustrated in an article about handling in the German *Das Motorrad* (No. 19, 2002). The test situations were two 'slalom' courses, one tight and slow (50-60 kph), the other open and quick (95-110 kph). Ridden by a professional tester, a Yamaha YZF-R1 was pushed through these courses, first in standard trim and then with the front wheel loaded with just 1.6 kg (of lead). On the slow course the 'loaded' wheel slowed the run down by 10%. On the fast course – imitating a series of fast curves on the road – the speed loss was 13%! Have you seen those Gold Wings with the front wheel and the fork lowers loaded up with disc covers, fancy lights, etc. I wonder, first, whether the riders notice any change in handling and second, whether they blame their tyres for it.

There is another advantageous aspect of radial tyres. Just remember that a tyre has to deal with two sets of forces – the traction (drive *and* braking) forces in the direction of travel and the side-forces generated by cornering. They are taken up by the plies. These run diagonally to both the traction and the side forces. You don't have to be a rocket scientist to know that the most effective way of taking up a force is in a direct line, not a diagonal one. Therefore, the short, radially direct plies of the radial tyre are much more efficient in dealing with side forces than the diagonally running cross-plies. Again turning this around, a radially constructed side wall can contain less material for the same performance as a cross-ply. Left at that, radial cords would be less efficient in dealing with tractive forces acting at right angles to them. Indeed, prototypic versions of radials were like chewing-gum when transmitting drive. However, these problems were solved by moulding in a 'breaker' belt – made of strong synthetic fibre or even steel mesh - around the tyre circumference and beneath the tread rubber. This gave a discontinuity between the flexible casing and the contact patch. That, though, led to high shear stresses. There again, the development of new materials with the necessary strength and anti-fatigue properties solved these problems.

So, it is possible to have tyres with plies running at various angles to the circumference – from 40° or so to the 90° of radial tyres. This does have some hidden consequences when you think that the plies provide the framework for the rubber. They determine the directions in which the stresses and strains act. Perhaps these effects can be illustrated by imaging a tent erected in a blustery wind. After all, a tent is a flexible material constrained by its plies – the guy ropes. Say that with a west wind the careful camper sets the ropes in a good way. The tent will bend in a particular way to the wind force. However, if the wind veers to the south, it will bend in a different way. It might bend more than before because the ropes can't accommodate the stresses in the same way. It is the same with tyres where the stresses and strains are not coming from the wind but from the road surface. Depending on the angle of the plies (ropes), the tyre will accommodate the forces differently. It will handle differently.[8]

Although advances have been made in manufacturing technology, apparently it is still more difficult to manufacture a faultless radial tyre than its cross-ply equivalent. Consequently, radial tyres are more expensive than other constructions, whether they are for cars or m/cs. M/c tyres were always more expensive than car tyres, if for no other reason than there being a much smaller worldwide market for them. The increasing use of radial tyres on cars has brought prices down, but they are not yet quite so common on m/cs. (After all, the m/c has to be designed from the start to use them).[9]

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[8] Tom French mentions one possible aspect of ply construction. For highly technical reasons (which means for reasons I don't understand!), cross-ply tyres have a tendency to 'climb' out of grooves, whereas radial tyres tend to run into the groove. Radial tyres are now widespread on modern heavy trucks. Therefore when they encounter minor grooves on the highway they tend to run down into them and stay there – and so, with their weight, make the grooves even deeper. Not having ridden m/cs fitted with radial tyres, I can't say whether they behave differently when encountering grooves or furrows.

[9] One contribution to high costs is the economics of mass production. Cars are not only vastly more numerous than m/cs but they are fitted with twice as many tyres and, on average, cover vastly greater annual mileages. Another factor is the sheer variety of m/c tyres – to fit not only the multitude of models but also the variety of specialist uses for m/cs. There are sports bikes, tourers, cruisers, commuter bikes, enduros, off-roaders, etc. Further, although passenger car weights vary substantially, there is … (cont.)

In one way, in spite of all these technical advances, the performance requirements of a modern tyre are no more than those originally conceived in 1845 – comfort for the rider and the reduction of rolling resistance. The first purpose is relatively straightforward. The rider *and* the m/c should be cushioned from the shocks and vibrations caused by many sorts of road surface. (We now know that this is a positive side-effect of the vehicle staying in contact with the road and maintaining grip and traction.) The rider needs protection so as to maintain control and to prevent rider fatigue and stress. The m/c also needs protection against fatigue where, at best, uncushioned parts soon get vibrated off or, at worst, metal fatigue causes the frame breaks. (Clearly tyres can't prevent damage caused by a boneshaker of an engine or a suspension as stiff as an iron bar.) Yet even rider-comfort is not just a question of vibration. Tyre noise is another source of stress that must be dealt with.

When power was not counted in horse- but in man-power, rolling resistance was a major factor limiting bicycle motion. It remained a primary factor in the early days of power assistance. Although ever present, it took on a secondary role as power developments allowed speeds above 80 kph (50 mph). At these speeds, wind resistance created more resistance to forward motion than tyres. The power increases encouraged no search for reduced rolling resistance. Times have changed, though. Environmental issues, the rising cost of fuel, the competitiveness of business, etc. demanded savings wherever possible.

M/c tyres were not exempt from all these pressures. Also, with more progress in m/c power and performance between 1965 and 1985 than in the 40 years before, m/c tyres just had to advance. As with most developments the progress was stepwise, addressing the various functions a m/c tyre has to fulfil. Of course, rolling resistance still had to be minimal but gradually another aspect – rolling promotion – came to the fore. Tyres had to be designed to bring that increased power on to the road – in a forward direction with acceleration and in a reverse direction with braking. However, the tyres also had to allow the motor(bi)cycle to turn – turn when it was accelerating and braking. So, comfort and low rolling resistance may still be the grand aims, but many functions of the tyre go into achieving these. An exploration of these functions can begin with the tyre acting as a spring.

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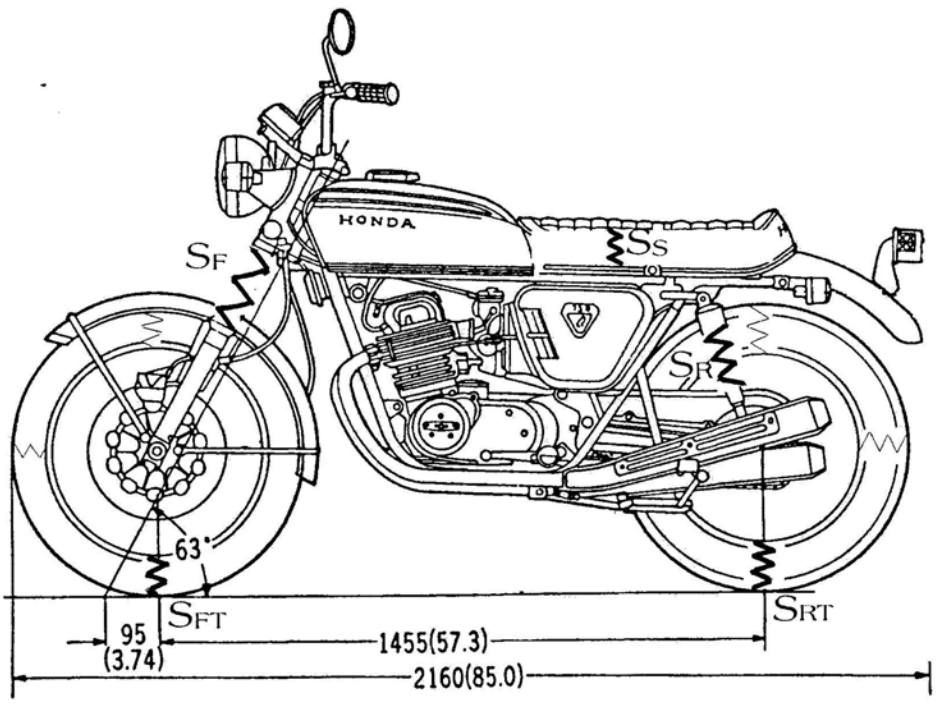
rarely the factor of 4-5 found with m/cs. Then, the definition of a m/c begins with an engine capacity above 50 cc. At the moment, there are production 1800cc machines – giving a capacity ratio of 36. I know of a 600 cc-production passenger car, but not a 21.6 litre production model! So, m/cs have a vast range of engine capacities – and with that weights and performances – and there is a vast range of tyres to meet those demands. On its web-site Continental lists 189 different m/c tyres. Pirelli has 247! – and *that* is without scooter, motocross or racing tyres. Yet, thousands of each can't be made and stored like spark-plugs – for tyres have a limited shelf life.

4. THE MOTORCYCLE TYRE AS A SPRING

Figure 3 shows a modern (well, 1968 *is* modern, isn't it?) m/c – quite different from the first two-wheeled vehicles like the penny-farthing bicycle which had no springing whatsoever. One of the first sops to comfort was a spring seat for bicycles (S_S in Fig. 3).

FIGURE 3: THE 'SPRINGS' OF A MOTORCYCLE



The first major development in comfort was Dunlop's bicycle with its pneumatic, rubber tyres. These gave the front tyre spring (S_{FT}) and the rear (S_{RT}). Motorisation of the two-wheeler demanded solutions to the added discomfort of speed. Because most discomfort was felt at the front, springing of the front forks (S_F) was, in one form or another, introduced to supplement that of pneumatic tyres and sprung saddles. The addition of rear suspension (S_R) came very late and was not widespread until well after WWII. Indeed, certain m/c manufacturers then made a virtue of models without rear suspension – with a 'hard tail'. (In some inscrutable way riding such a m/c was supposed to say something about the masculinity of the rider. I've got nothing about maintaining tradition, but a *real* man would be one who rode such a m/c on tyres designed at the same time as the m/c!)

Although m/c suspension is a topic for itself, it is relevant when discussing m/c tyres – and just how many flexible and sprung functions there are in a m/c. Most riders think that the main function of suspension is to protect the rider's backside from the insults of rough and uneven surfaces. Its main purpose, though, is to keep the wheels in contact with the road. No matter what qualities are built into a tyre, they are worthless if the tyre is not on the tarmac. Friction between rubber and air is remarkably insignificant.

The ability of a vehicle to steer or gain traction on air is also rather low. Indeed, although Thomson and Dunlop spoke about ride-comfort, they and we probably think of the pneumatic tyre cushioning the rider – from the effects of the two-wheeler bouncing *up* from the road. However, the greater contribution to comfort – and 'rideability' – is the contribution of the tyre in keeping the vehicle *down* on the road. Today's m/cs have several systems acting as springs. (The CB 750 in Fig. 3 has 5.) Under the dynamics of riding any or all of them can be compressing or expanding – and all the momentary changes express themselves in the place where the m/c meets the road – the tyre contact patch.

Although most riders do not consider the spring function of tyres, it can make up about 10% of the overall 'suspension and shock-absorber' system. In racing circles a change of tyre can deliver a necessary fine tuning of spring rates. (Care has to be taken in terminology. The rubber compounds can vary from soft to hard in respect to their grip/wear properties. However, the tyre construction – mainly of the side walls – can vary from soft to stiff, and affect its flexibility or spring-rate.) John Bradley's simple formula:

$$OSR = (FSR \times TSR)/(FSR + TSR) \quad \text{(Equation 1)}$$

gives the overall spring rate (OSR) from the fork spring rate (FSR) and the tyre spring rate (TSR). A few examples can illustrate the combined effect of suspension springs and tyres, as in Table 2.

TABLE 2: MOTORCYCLE SUSPENSION AND TYRE SPRING RATES

TYRE & SPRING COMBINATION	SPRING RATE (kg/mm)*			
	FSR (fork spring rate)	TSR (tyre spring rate)	OSR (overall spring rate)	REDUCTION (OSR vs. FSR)
A	1.8	20	1.65	8%
B	1.8	12	1.57	13%
C	1.2	20	1.13	6%
D	1.2	12	1.09	9%

* Force needed to compress spring by 1 mm. The lower the rate, the softer the spring

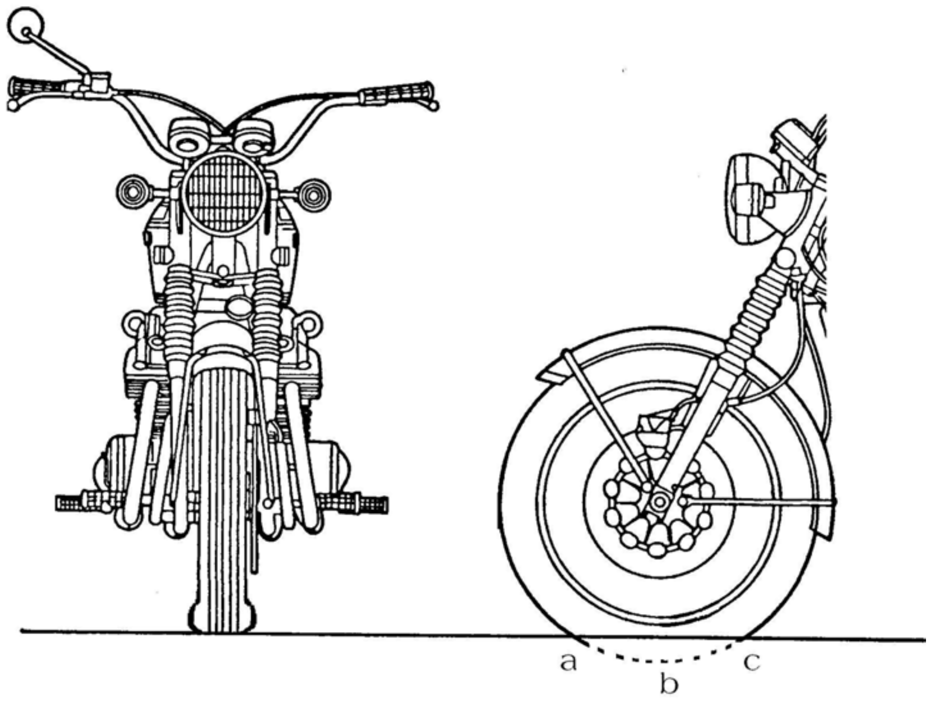
Table 2 shows the combined spring rates of two suspension springs, one harder (1.8 kg/mm, A and B), one softer (1.2 kg/mm, C and D) than the other, with a hard (20 kg/mm, A and C) or soft tyre (12 kg/mm, B and D). Although the tyres need 10-16 times the force to compress them, they still make the whole suspension system softer. It is obvious that a softer tyre (TSR 12 kg/mm) makes any system softer overall (by 13 or 9%) than a hard tyre (TSR 20 kg/mm). However, the rate of a harder suspension spring (FSR 1.8 kg/mm) is reduced proportionally more (8% or 13% vs. 6% or 9%) than that of a softer suspension spring (FSR 1.2 kg/mm).

So, changing from the original tyre fitted by the manufacturer may change the overall suspension rate if the spring rate of the new tyre type differs markedly from the original. Such a change may make the rider feel more comfortable – or less. It might change the cornering characteristics – for better or worse.

5. THE CONTACT PATCH

So, now it's time to look what happens at that contact patch or 'footprint'.[10] (In all of the following discussion, with illustrations, it is assumed that the tyres have the correct load-rating for the m/c and are correctly inflated.) Before reading on, though, take a thick rubber band and rapidly stretch and relax it for a couple of minutes. Putting it against some cool skin will show that it gets warm. This is due to *hysteresis*. The energy put into stretching and flexing goes into the molecular strands of rubber to uncoil them. When the tension is released the stored energy is not immediately given back but lingers in the rubber. Most flexed materials show this hysteresis to a greater or lesser extent. So, when tyre-material flexes, stretches and compresses it gets warm.

FIGURE 4: TYRE-ROAD CONTACT PATCH



FRONT VIEW SIDE VIEW

The front view of the m/c on the road in Figure 4 shows a familiar picture, albeit exaggerated, with the tyre bulging out (stretching) under the weight of the machine. Obvious without further illustration is the fact that the tyre is not bulged before and after the contact patch. So, during each revolution of the rolling wheel, every part of the tyre side wall flexes out and in. Perhaps that seems too obvious and trivial to warrant any attention. However, how often can that happen? Take a 4-cylinder Gold Wing.

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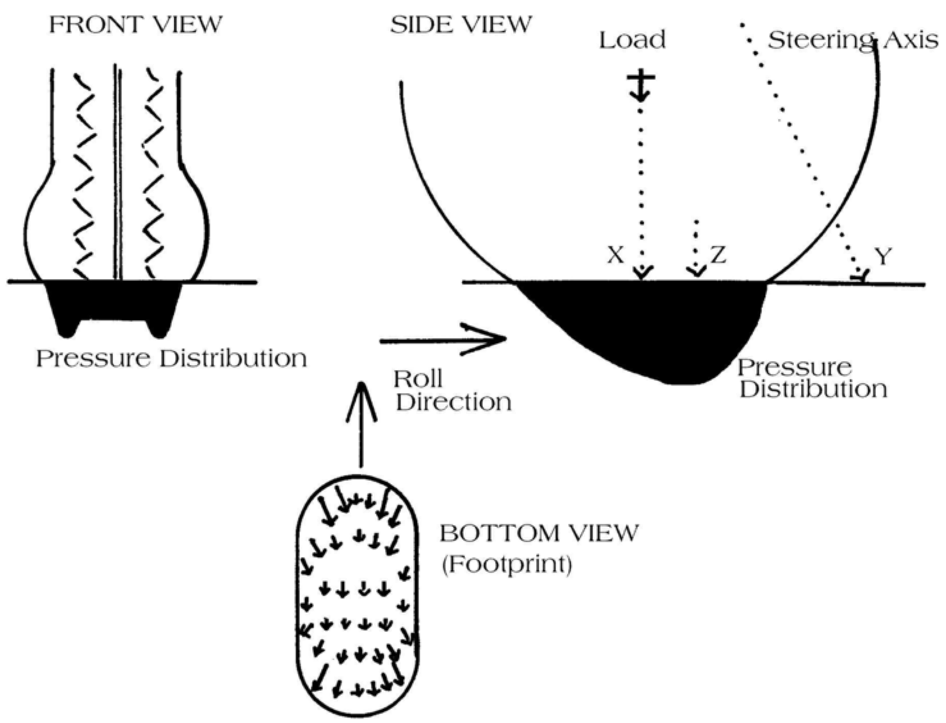
[10] Stand the machine on glass and view it from beneath. You see the contact patch or 'footprint' as it tends to be called in USA. Anglosaxons sometimes call tyres 'boots'. If they are boots, then they are about size 4½!

Depending on the model, the rolling circumference of the tyres is 1933-2057 mm (around 2 metres). These touring m/cs are easily capable of cruising down the highway at 160.8 kph (100 mph). At this speed the tyre rotates 80'400 times (1'340 rpm, without slip) in an hour. So under the rolling m/c's load, the side walls are flexing more than 22 times a second – flexing and getting warm. (Try doing that with a rubber band!)

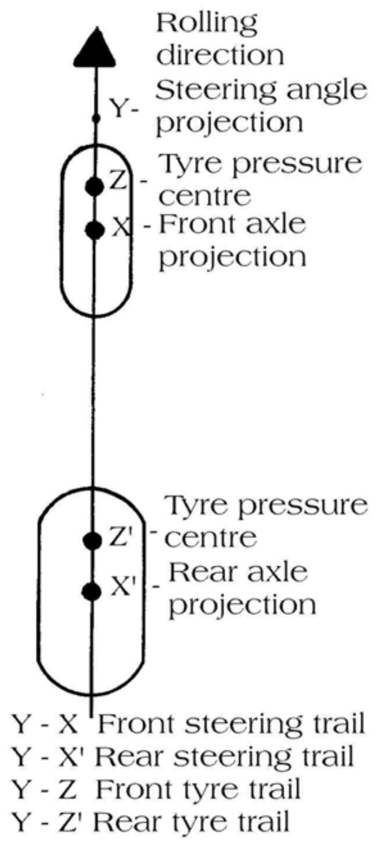
The side view in Fig. 4 shows how the load deforms the tyre from its *a-b-c* natural shape. The rubber of the leading edge is forced to travel not from *a* to *b* to *c* but from *a* to *c*. It needs no expertise in Euclidean geometry to see that the distance *a-c* is less than that from *a-b-c*. The tread rubber is compressed into the patch and then expands out of it. This again generates heat. However, it is not just a case of the rubber stretching and relaxing. The way in which the tyre passes through the contact patch affects the manner in which the load is transmitted to the road surface. This is illustrated in Figure 5.

FIGURE 5: LOAD DISTRIBUTION AT THE CONTACT PATCH



Because of the side-bulge, the load-carrying side-wall approaches the road at a slight angle, as can be seen from the front view of a rolling tyre. This means that the greatest force is exerted at the edge of the tyre. The side view shows the effects of that extra rubber getting compressed into the contact patch. Because of the elasticity of the tread, the load-forces reach their peak some way back from the leading edge of the contact patch and then gradually fall away as the tyre rotates. A schematic force diagram of the footprint shows that the forces acting on the tread are proportionally greater near the leading edge and outside – not at the centre of the contact patch.

FIGURE 6: THE FOUR TRAILS



Going back to Fig. 3, it showed the trail at the front end. Although the steering head of the CB 750 is about 80 cm above the road, geometrically the steering is around the virtual pivot where the raked forks (at 63°) project to the road. The centre of the tyre 'trails' 95 mm behind this. This trail gives a castor effect – just like on furniture or the supermarket trolley. The weight acting on the centre of the contact patch trails behind the pivot point and so induces a self-aligning force. The trail is one of the factors which determines the sort of steering a two-wheeler has. It also determines straight-line stability. If the trail is long – as with a raked-out chopper, the steering is slow. The steep, little raked steering of a sports bike has, with its short trail, a much quicker steering response.

Returning to Fig. 5, Y is the steering head projection. X is the centre of the contact patch. So, here the steering trail is Y-X, determined by the geometry of the rolling chassis. It is the value that is given in most m/c specifications. However, X is the load-centre of the standing m/c. This is all very well, but Figs. 5 and 6 show the m/c rolling on a billiard table – so smooth is the surface. Real Life isn't like that. Roads show every kind of irregularity, full of holes and ridges as well as surfaces changing in texture and grip. It is not possible to discuss the consequences of these many possibilities but Figures 6 and 7 can show the principles involved.

Once the m/c is moving the weight distribution changes. It becomes centred on Z. Depending on speed and whether the m/c is lifting under acceleration, diving under braking and/or turning, this functional trail, the *pneumatic tyre trail* Y-Z, is continually shifting. So, a moving m/c does not just have one 'trail' that determines both the general and momentary steering characteristics – it has four, two of which are constantly moving! These are illustrated in Fig. 6. It is often forgotten that the rear wheel (with trail Y-X') as well as the front (with trail Y-X) also has a castor function in respect to the steering pivot – and so can cause problems in steering and handling. Many amateur tuners have spent much time and even more money trying to solve such problems at the front end, only to find that the faults lay at the back. Then, just as the front tyre has the pneumatic tyre trail of Y-Z, so does the rear with its pneumatic tyre trail Y-Z'.[11]

[11] Actually it wasn't quite correct to suggest that the other trails – Y-X and Y-X' – do not change. Under extreme conditions the frame geometry can change. Under strong braking, for example, the steering head can 'tuck in' and the angle steepen – one of the problems of inadequate frames 25 years or so ago.

FIGURE 7: LOAD DISTRIBUTION AT THE CONTACT PATCH
(on rough road surfaces)

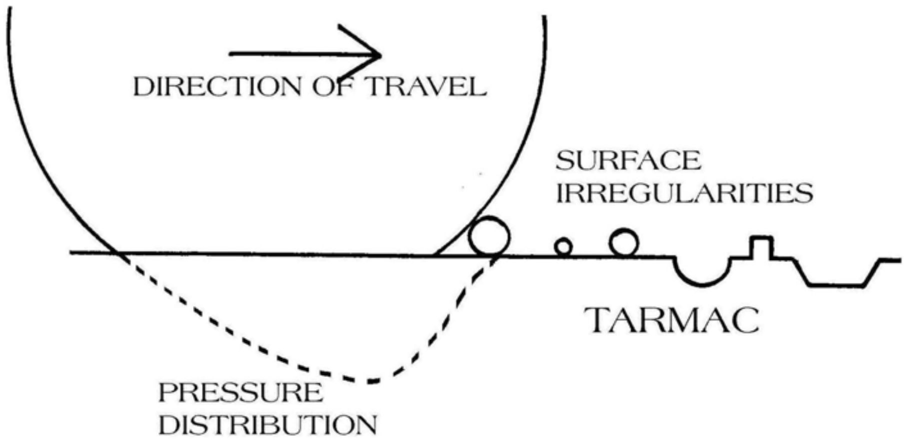


Fig. 7 shows a side-view of a tyre approaching typical surface irregularities. The tyre is about to pass over a protruding stone. In practical terms the point where the tyre first touches the stone becomes the leading edge of the tyre. The load on the tyre then starts being distributed on to the stone. It is shifted forward – and with it the centre point of maximal tyre pressure (Point Z in Fig. 5). Here you will have to imagine a movie sequence – as the tyre passes over that stone (when Z moves back again) and then reaches the other stones. These cause Z to constantly move forward and back. Then the tyre reaches a depression. For a moment the physical leading edge of the tyre contacts nothing. The load can then be distributed only on the tyre still in contact with the road – that is, further back. So here the centre point of the load distribution moves behind the original Z-point. So, as the tyre rolls over these imperfections the castor is constantly changing. This introduces a vague feeling in the steering. Obviously, the bigger the irregularity in relation to the diameter of the tyre, the bigger will be the dynamic shift in Z. A rough road would not be felt through a large tractor wheel. However, a small scooter wheel would feel very wishy-washy on the same road.[12]

The way in which the pressure at the contact area is distributed also affects a tyre's response to other irregularities in the surface. Some of these are illustrated in Figure 8. This is a composite sketch, showing just some of the surface effects – white lines, tar over-banding used to repair cracks in the tarmac and rain grooves scored into the road to reduce the risk of aquaplaning by cars. The m/c tyre may run partially or fully on over-bands. That in itself is no problem – except that tar has a much lower coefficient of

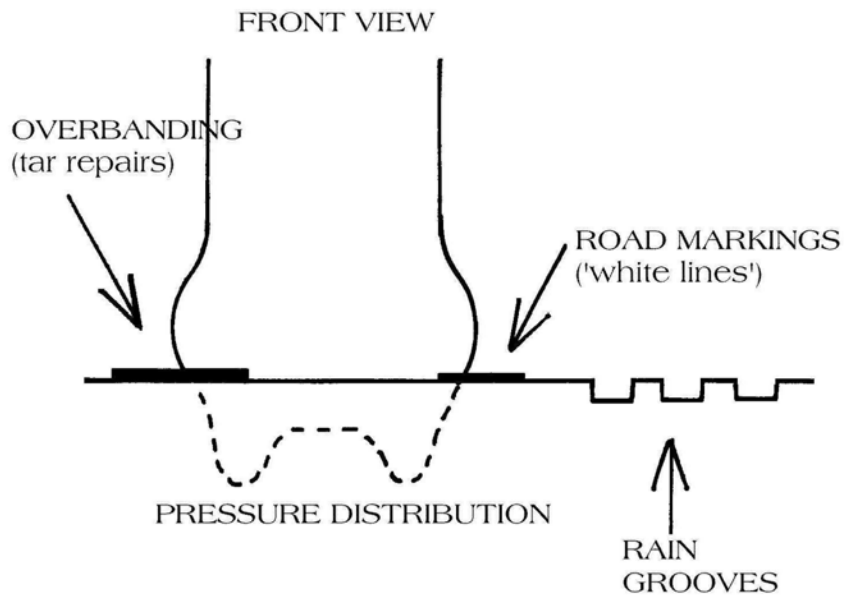
[12] To understand another problem, continue to imagine the tyre moving over that stone. Let us also imagine that the frictional force between the stone and tarmac is virtually zero but considerable between the stone and the tyre. The stone will be impressed into and gripped by the tyre and, as the wheel rotates, will slide with it – until the tread rolls off the road. Moving at the speed of the tyre the stone will then be catapulted backwards – perhaps into the windscreen of a following car or the face of a m/c rider wearing no face protection. *Is* there any m/cyclist out there who has survived a facial stone strike when following a car at 80 kph (50 mph)? After all, the impact speed will be nigh on 160 kph (100mph)

friction than tarmac. Indeed, it offers virtually no grip when wet. At any moment the frictional force acting on the contact patch is given by:

$$F = \mu \, x \, W \quad \text{(Equation 2)}$$

where μ is the friction coefficient between the tyre (that is, the contact patch) and the road surface and W is the *momentary* weight loading on the tyre.[13] The 'footprint' in Fig. 5 shows how the forces are distributed in a standard situation. When, however, the situation is not standard – and the coefficient of friction varies throughout the footprint – then the forces will be irregular. Also the fact that white lines and repairs may rise up several millimetres adds to the disturbance. The contact patch will be pulled and pushed this way and that – squirming around to make the steering feel vague and not quite controlled.

FIGURE 8: LOAD DISTRIBUTION ON VARIOUS ROAD IMPERFECTIONS



Rain grooves do not have quite the same effect. M/c tyres tend to be narrower than car tyres. Therefore there is not enough width to spread over enough groove to stabilise the tyre. The tyre can momentarily settle into grooves – to remove the feeling of control – only to pop out again. Also, a particular tyre's tread pattern may 'fit' into grooves better than another. Again, where the tyre touches the ridge, there is frictional force. The air in the grooves has zero friction. So, the footprint again experiences varying forces. All of this is worse on a m/c than a car because so much of a m/c's stability depends on that front wheel. One or another of these effects could affect a car tyre. However, a car is stabilised at four points and it is improbable that all four will suffer from the same momentary influences.

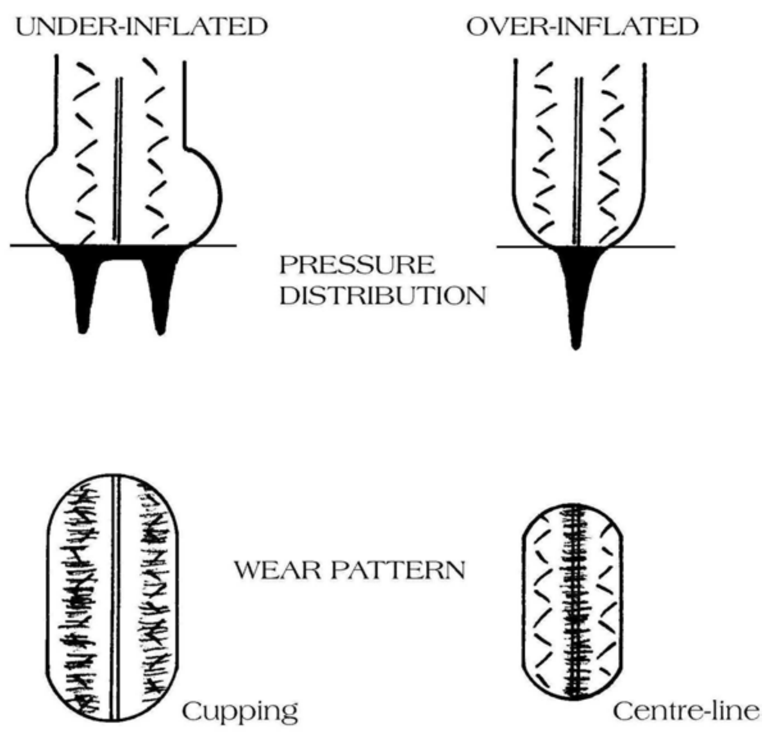
[13] It is the *momentary* weight because the static weight is constantly changing as the attitude of the moving m/c changes every moment. The weight distribution changes as the m/c passes over surface irregularities, accelerates, brakes, ascends or descends. So, if the weight acting on a contact patch changes by 20%, then the momentarily available frictional force will also change by 20% - instantly.

6. INFLATION PRESSURE

There was a time when handling problems could be put down to inadequate frames. Indeed, some were no better than ironing boards made of chewing gum. Since manufacturers developed designs and materials that overcame these weaknesses, much more attention has been given to tyres and their match to the machine. While it was once rare, today the first moments of motorcycle development include concurrent development of its tyres. The planned use, performance and weight of the m/c determine the nature of the tyres. This includes the type of construction (cross-ply, radial, tubed, tubeless), the thickness of the side walls, the strength and material of the cords, the elastic and wear properties of the rubber, the type and depth of tread, etc. which determine the load-carrying capacity and the speed at which of the tyre may be safely used.

Well, that is not quite the whole story, because these properties can only work when the tyre is inflated to its designated pressure. The science that has gone into producing that ring of rubber is useless if the tyre is incorrectly inflated. There are riders who invest inordinate amounts of time playing around with the settings of the air-assisted shock absorbers of their front and rear suspension, yet do not spend two minutes of checking the other two air-assisted shock-absorbers – the tyres.

FIGURE 9: LOAD DISTRIBUTION AT THE CONTACT PATCH OF INCORRECTLY INFLATED TYRES



Let's take a simple example. Assume that the tyres on that CB 750 in Fig. 3 have a tread depth of 6 mm when new – but they wear down to the legal minimum of 1.6 mm. (Here we are not talking about a safety limit – just the legal limit.) Let them be a bit under-inflated as well, so that with these soft, worn tyres the front of the bike sits 10 mm lower than in the show-room. A bit of maths shows that the m/c trail changes from 95 mm to 75 mm – a shortening of 21%. Clearly the pneumatic trail effects of the tyres will be affected as well. Therefore it should be no surprise if the handling and steering characteristics of a machine fitted with soft, worn tyres differ somewhat from those intended by the m/c and tyre manufacturers. These are not the only effects of incorrect inflation pressures. Figure 9 shows more – in some somewhat exaggerated front views.

With under-inflation, they bulge more under the m/c weight and the elastic properties of the tread force the weight more into the edge of the tyre. Because load is fixed, more weight at the sides means less weight at the centre. (In extreme cases the centre may hardly touch the road.) One consequence is relatively more wear at those edges, as shown in Fig. 9. Long-term under-inflation for the load on the m/c therefore tends to form a ridge or 'cup' of less worn rubber around the centre. (No, there are no free lunches! The tyre is not wearing better because more is lost from the sides.) This cupping can have handling consequences. The steering of a two-wheeler depends on the rounded cross-section of the tyre. The machine must be able to roll smoothly from one side to the other. Cupping produces an irregularity that can upset this rolling and, when not instability, certainly an indefinite 'feel' on going in and out of a lean. Yet further effects will be felt in the wet. The centre of the tyre is the most important part for ejecting water from the contact patch – and this ejection depends on the pressure between the tyre and the road. Now, less tread may have been worn away on a cupped tyre but without the normal pressure of the tyre the ejection of rain-water will be impaired. A cupped tyre changes the feel of the bike in the wet – and may promote aquaplaning (which will be discussed later).

Over-inflation prevents a tyre forming a normal contact patch. (If a tyre is over-inflated to the extreme, then the rider sets all of John Dunlop's work to naught. He/she might as well fit an iron hoop to the m/c!) Side walls that have been designed to contribute to the handling and steering characteristics function inadequately. Shock-absorbing and spring properties are impaired. With a reduced contact area, the weight of the m/c concentrates along that centre line, causing excessive wear there. In the wet, the greater load on the smaller contact area will help eject standing water but the worn tread will not. More than as a result of under-inflation, the rider is throwing money away with over-inflation. A correctly inflated tyre should wear relatively evenly during general use. An over-inflated tyre will become illegal much sooner, causing the rider to throw away good rubber still to the side of centre.

Those two factors, weight distribution and wear are linked by a third – tyre temperature. One is the complement of the other. Fig. 9 shows that wear distribution follows weight distribution. A graph of the temperature distribution across the tyre tread would show the same identity. So, an under-inflated tyre runs much hotter on the outside wedges of the tread and cooler in the centre. The heat generated by the over-inflated tyre concentrates in the centre – and may be excessive. Because friction is greater with warm rubber (unless the temperature is so high as to damage the rubber) and less with cool rubber, the grip across a falsely inflated tyre will vary as the m/c is leaned this way or that. At worst, this may lead to false estimates about how much grip is available at any moment. At best it may be unsettling.

Under-inflation is more common than over-inflation. First, over time no tyre has ever pumped itself up but many lose pressure. Also, riders are not always conscientious about matching pressures to loads. Just one of many consequences of under-inflation is an effect on the tyre's rolling resistance. John Bradley discusses this dependency. Although the science isn't fully worked out, there are some empirical formulae for linking these. For example, up to about 165 kph (102 mph) the power lost to rolling resistance is given by:

$$W[0.0833.V + 0.176.V/p + 1.58.V^3/(10^5.p)]/3600 \quad \text{(Equation 3)}$$

where p is average cold tyre pressure (kg/cm^2), V the riding speed (kph) and W the total m/c weight (kg).

Consider a large touring m/c – a Honda GL1200AH. Its rider is moderately built – and conscientious about wearing protective gear. He weighs in at 90 kg ready-to-ride. He usually checks his tyre pressures, both when riding alone and going on holiday with a fully laden bike. However, once he forgot to change the pressures recommended for solo riding to those for full-load riding – and thrashes down some foreign highway at 160 kph (100 mph) for two hours, with the tyres set for solo riding. The effects on rolling resistance – and the power losses involved – are given in Table 3.

TABLE 3: POWER LOSSES DUE TO ROLLING RESISTANCE*

	A 90 kg rider	B max. load	C max. load
Total weight (kg)	**444**	**530**	**530**
Correct tyre pressure (kg/cm^2)			
Front	**2.25**	**2.25**	
Rear	**2.50**	**2.80**	
Incorrect tyre pressure (kg/cm^2)			
Front			**2.25**
Rear			**2.50**
Power consumed in kW (hp)	**6.47 (8.74)**	**7.38 (9.97)**	**7.72 (10.43)**
Increased power required			
Above A kW(hp)		**0.91 (1.23)**	**1.25 (1.69)**
Above B kW(hp)		**-**	**0.34 (0.46)**

* Honda GL1200, partly or fully loaded, with various tyre pressures

Riding solo at this speed (situation A) the rolling resistance costs 6.47 kW. That is nearly 7% of this m/c's maximal power. With a loaded bike and recommended tyre pressures (situation B) the power loss increases to 7.38 kW (about 10 hp). The power cost of overcoming the rolling resistance of the under-inflated tyres is even more – 7.72 kW. This means that the forgetfulness to adjust the pressures from the recommended solo levels to those for fully loaded riding costs an extra 0.34 kW – or about ½ hp.

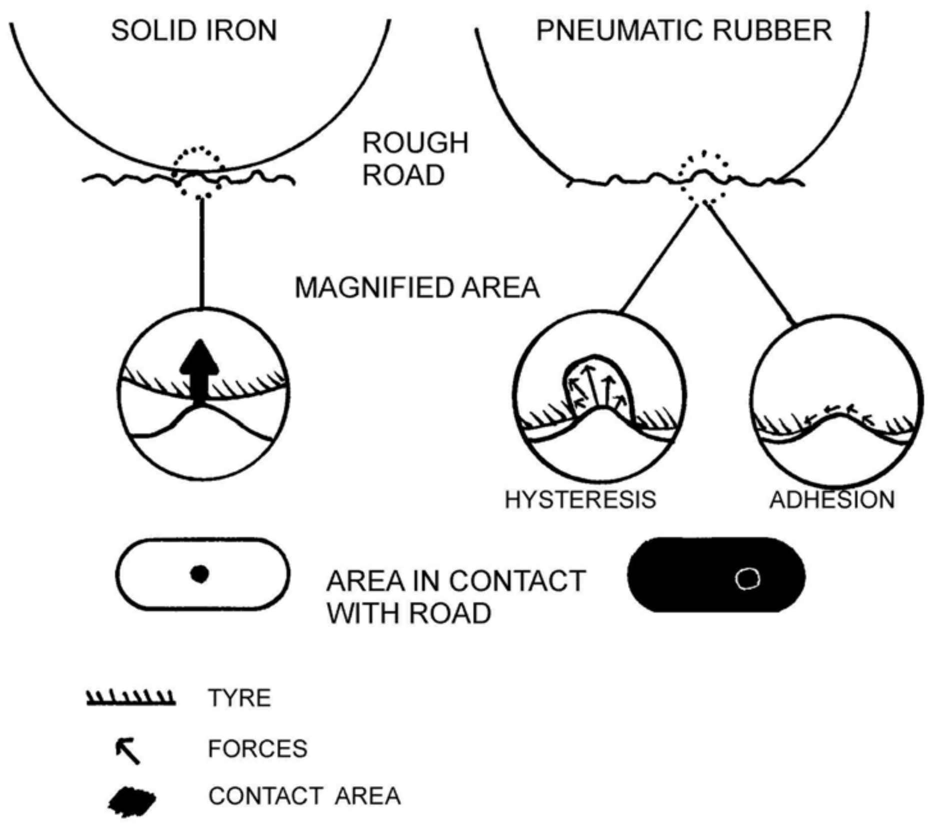
Half a horsepower doesn't sound very much, so perhaps it can be looked at another way. Assume that rider with that under-inflated rear tyre does actually arrive safely at his camping place. He gets out his wee camping stove to make his first tea – filling the kettle with a pint of water. Impatiently he waits about 8 minutes for the water to boil. Well, to boil in 8 minutes takes about ½ hp! Would you think him very bright if he put his tyre on the camping stove for 8 minutes? What about for 2 hours? That is what he was doing with those under-inflated tyres. Is that what the Irish rider metaphorically did, as related in the Foreword?

7. TYRE MATERIALS

As suggested before, although the properties of comfort, noise and rolling resistance remain significant targets for improvement, the advances in vehicle performance and driving speeds have pushed the question of adhesion into the foreground. Over a wide range of surfaces and conditions a tyre is expected to transmit tractive and braking forces and provide control of the vehicle's direction. Expected without slip or slide – because few of us are Grand Prix riders.

First, these racers have tyres designed for that singular purpose of providing traction, braking and control. The tyres only have to last about 150 km, not 15-25'000 km. They do not have to carry several hundred kilograms of weight. They run on surfaces that are reasonably constant – certainly not like some of the road works met in daily riding. They do not have to bump up and down kerbs, stand for hours on car-parks in Saharan temperatures or suffer the many other indignities we impose upon them. Not to be forgotten is that cost is no object for such tyres.

FIGURE 10: ADHESION MECHANISMS AT THE CONTACT PATCH

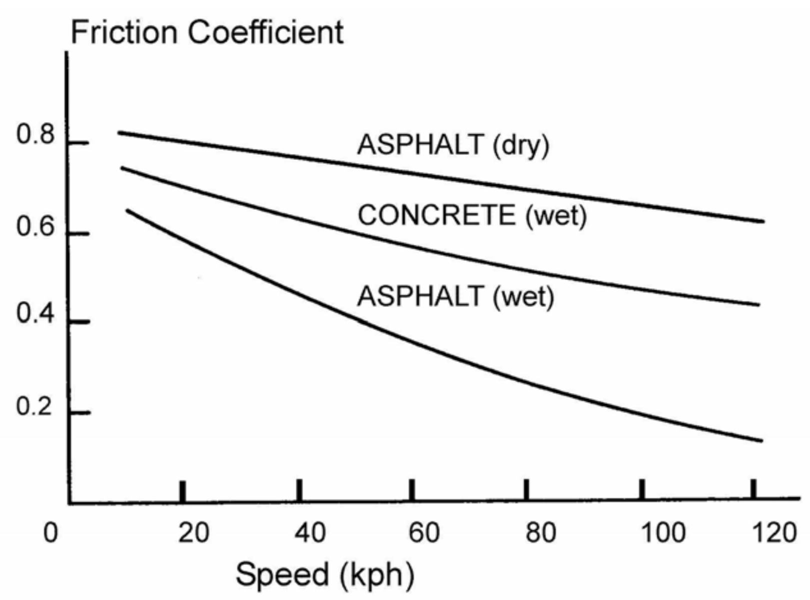


Second, our tyres are expected to perform conservatively because we do not have the skills of racers. It is awesome to watch them in action and the way that they can push the inherent properties of the tyres to those limits. Even more awesome, though, is when even they make a small mistake by overstepping those limits. Within milliseconds the mistake is corrected (well, mostly) and the m/c continues its merry way. Auntie Mabel driving her Volvo does not have these abilities. She is unable to recognise the limits. Therefore Auntie Mabel's tyres are not designed to be knowingly taken to their limits, but to be forgiving when she exceeds *her* less than expert limits. It is the material and design of that contact patch that does this.

It is not by chance that we call tyres 'feet' or 'boots' - because the places where an object or a creature contacts the ground are called feet or are shod with boots. It will be no surprise, therefore, to learn that researchers examining the factors providing grip have turned to nature. Studies of camel feet led to improvements in tyres for wartime desert vehicles. Much use has been made of studies of the gecko. This is a tiny lizard found in tropical countries. (It is always good to have a few in your hotel room – they feed on bugs and mosquitoes – and they provide endless, harmless amusement.) They race up and down walls and, seemingly defying gravity, across ceilings. They accelerate, brake and turn and, apparently impossible, they can do that on vertical glass windows. Knowledge of the microstructure and adhesion of the gecko's feet led to a greater understanding of the importance of the microstructure of a tyre contact-patch.

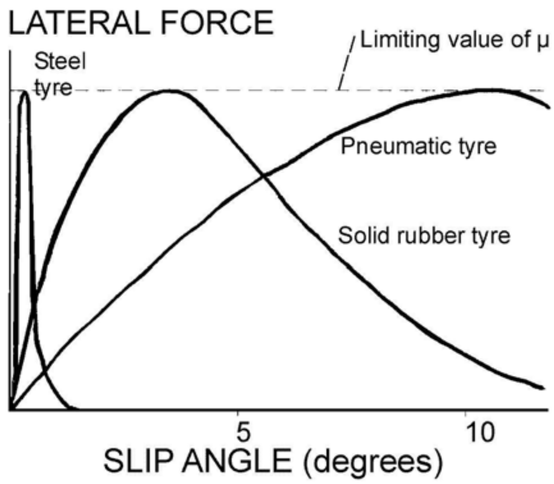
Adhesion – sticking to the road – might be best understood by describing a situation where there isn't much. An iron wheel of yesteryear is a good placed to start – and one is shown on the left of Figure 10. The iron wheel hits a little, protruding stone. This generates a local force which, because of the wheel's inflexibility, pushes the wheel up. The whole axle weight then rests on the minute contact patch between the iron and stone. Recalling Equation 2, the high value of W – the weight – should give lots of frictional force.

FIGURE 11: EFFECT OF SPEED ON COEFFICIENT OF FRICTION BETWEEN TYRE AND ROAD SURFACE



It should, but the coefficient of friction, μ, between stone and iron is low. So, little frictional force develops to 'hold' the wheel on that stone. It slips off. A further factor comes into play now. Coefficients of friction can fall sharply when the two contacting surfaces are already moving – more speed, more loss. This effect for tyres on various surfaces is illustrated in Figure 11. Although this speed-effect is considerable, that of an iron wheel is even more dramatic. Figure 12 illustrates just how quickly slight slip-angles can lead to a precipitous drop in the amount of lateral force that can be sustained. So, the iron wheel slips faster and faster – until it comes up against the next irregularity. (Here we are only talking about slides of a few millimetres. The consequences of similar factors could be experienced directly by trying to dance vigorously on a stone floor when wearing hob-nailed boots.)

FIGURE 12: RELATIONSHIP OF LATERAL FORCE AVAILABLE AT VARIOUS SLIP ANGLES



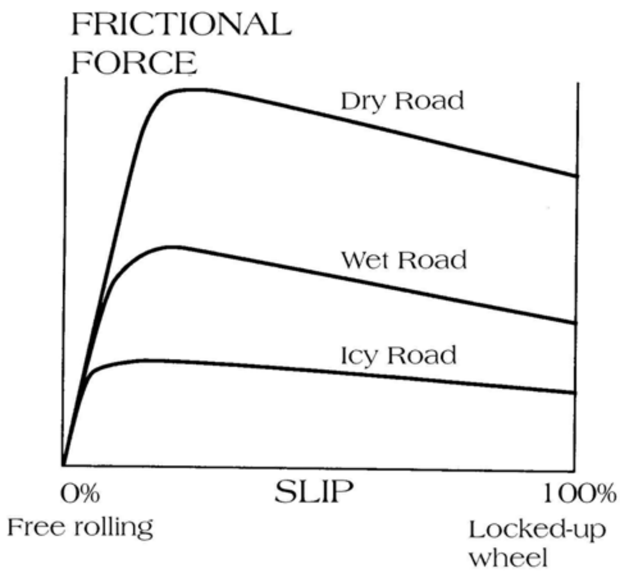
Two processes operate with a pneumatic rubber tyre, as shown on the right of Fig. 10. Because of the elasticity of rubber, the shock force of hitting the stone does not lift the wheel, but it is absorbed as a tread deformation. Then, because of that hysteresis mentioned earlier, not all of the absorbed energy is returned immediately – so this presses the tread back on to the stone, and grips it. The second process is the adhesion itself. When the tyre in contact with the stone wants to slip, with its high coefficient of friction the rubber of the tread clings to the surface. Through chemical and physical forces the molecules of the tread and the road stick together. The frictional forces generated actually reach their maximal values when the rubber slips a little – microscopically tearing a few molecules of rubber away as it does it. We usually call the long-term consequences of this slippage ‘wear’. However, in the short-term – in the *here-and-now* – this slippage is necessary.

Figure 13 shows how this develops in a braking situation. If the m/c is free rolling, with no positive or negative traction, friction doesn’t come in to play. As the brakes start slowing the wheel, the tyre has to slow with it. It does this by dragging on the road – as much as the available friction allows. As this tendency to slip develops, the frictional force increases *very* rapidly. It reaches its peak (70-90% of the load) when there is about 15% of slippage *at the molecular and surface levels*. Thereafter it drops only a little. Obviously the frictional force is greatest on a dry surface. What is noteworthy is that even when the wheel is locked up – with 100% slip – most of the frictional force is there[14]. It is just not enough to brake the vehicle. On wet roads, and even more on icy roads, it peaks at a much lower level – and somewhat earlier. This is relevant for driving in those conditions. Most people know that there is little peak friction but not all are aware how quickly the tyres can break past this peak.

[14] Slippage is given by: Slip % = 100(1-rw/V), where r = effective rolling radius of tyre, w = angular velocity of tyre, V = forward velocity.

These two aspects give tyre designers some choice in the materials to use for a particular tyre. Fig. 12 shows that even rubber tyres running at high speed on, say, wet asphalt are not immune from marked reductions in grip. Of the two processes providing traction (positive or negative), adhesion is particularly susceptible to a drop in friction in the wet. Therefore, a tyre for wet conditions can be made with high-hysteresis materials to promote this provider of grip. Such tyres are expensive and show poorer wear. In GP racing, cost and, until the chequered flag, wear are irrelevant. So, ranges of tyres providing many levels of grip are available in the pits.

FIGURE 13: FRICTIONAL FORCE AND SLIPPAGE DURING BRAKING



They are not available to us – because most of us never go into that territory to justify their use. Figures 12 and 13 show just how much – or how little – slippage a pneumatic tyre can tolerate on various surfaces and with various steering or braking inputs from the driver/rider. It *is* very forgiving, still offering lateral and forward grip when the inputs are excessive. This is one of the design demands for tyres – to tolerate the little lapses and errors of the average driver/rider. There is no market for road tyres that allow average speeds of 150 kph (95 mph) in pouring rain, as in the recent Brazilian GP.[15]

Tom French summarises the material demands as follows:

> "Use a material with a high frictional value for the range of surface and wetness conditions to be met, mould this on to a base which, though relatively rigid, is in itself sufficiently flexible to fit partly to the surface profile. It then should be able to

[15] There is a market for 'winter' car tyres in the mountains. They are obligatory in some Scandinavian countries and certain regions of Austria. Here in Switzerland they are not obligatory but expected. We switch to these in late Autumn and back to 'summer' tyres in Spring. Made of different materials, they produce their grip at lower temperatures and on slippery surfaces – but wear is inferior. (In winter, if we lose traction and, say, block an Alpine pass or cause an accident with 'summer' tyres, we will certainly get fined and may be held responsible for all ensuing costs, including getting the road open again.)

> resist local distortions and slippages without causing the whole of the contact patch to slide and slip with them."[16]

That is easier said than done – in view of the many compromises required to optimise the many aspects of a tyre's performance. Wet grip requires materials with high hysteresis. This allows the tyre to cling to the road surface by soaking up the energy involved in the thousands of little shocks of surface abnormalities. That's good. However, that absorbed energy heats up the tyre – and can overheat it. That's bad. Heat increases wear and excess heat could lead to tyre failure. Then, there is a hidden aspect to this compromise. The heat energy that acts positively to provide grip but negatively perhaps to over-heat the tyre has to come from somewhere. There is only one source for it. The first guess would be that it comes from the power driving the wheel, in the form of rolling resistance. That, however, is not the full story because that wheel power is derived from the engine. So, the good grip in the wet and the possibility of over-heating in the dry obtained with high hysteresis materials is at the cost of fuel economy.

However, there is one parameter over which the compromise between grip and rolling resistance can be narrowed. That is the one of deformation frequency. Figs. 7 and 10 show a tyre rolling over the many macro- and micro-irregularities of a road surface – encountering innumerable deformations during each revolution of the tyre. Such deformations are occurring at relatively high frequency. Recalling the chapter about the contact patch (Chap. 5, Fig. 4), however, shows that the greatest deformations (and generation of heat and rolling resistance) occur as the tyre passes through the contact patch – but only once during each revolution. So, these are occurring at relatively low frequency.

Recent developments – again spearheaded by Michelin in its car tyres – have produced tyre materials that show high hysteresis (good for grip) during high frequency deformation yet have relatively low hysteresis (good for low rolling resistance and, therefore, fuel economy) during the low frequency deformations, as at the contact patch. These materials were obtained by replacing some of the carbon black in the rubber recipe with ultra-fine silica. It is claimed that wet grip can be retained while reducing rolling resistance by 20%. This in turn can give a 5% saving on fuel. Whether these claims can be substantiated for the new (Summer, 2002) silica-containing Michelin "Pilot Road" m/c tyres and those recently launched other companies remains to be seen.

Not to be forgotten is the fact that the tyre material is only part of the solution to getting good wet grip. Clearance of water under the contact patch by the tread profile is also important. This, and the compromises involved here, will be addressed later.

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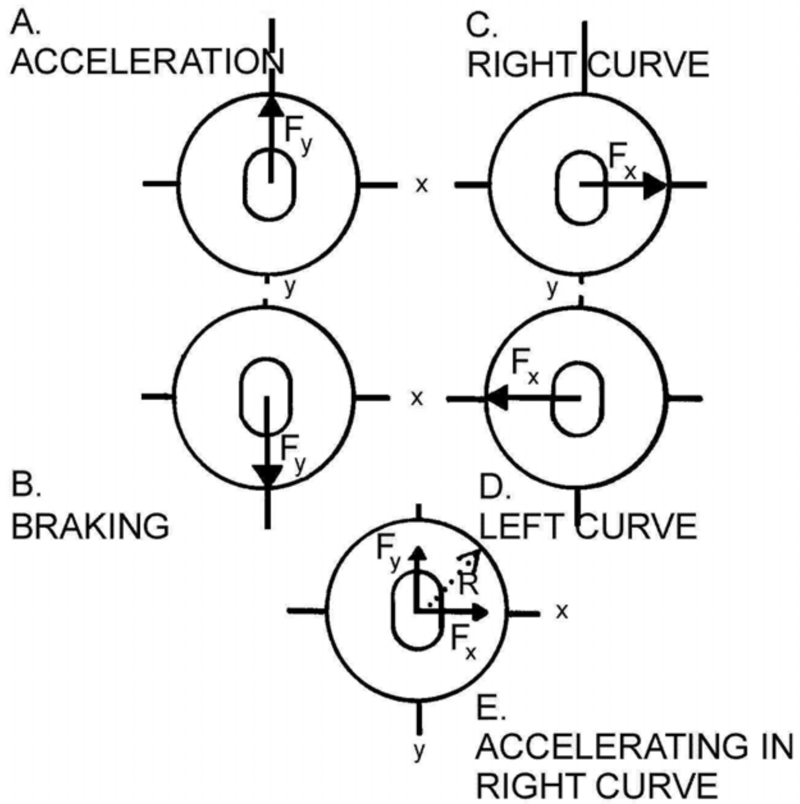
[16] French relates a nice, true anecdote to illustrate this – and to show that high-tech does not always deliver the best solutions. There was a national competition, with a large cash prize, for an invention to reduce the risk of blind peoples' sticks slipping in the wet. (Serious accidents had resulted from this.) Many august institutions and recognised researchers burned the midnight oil in many an industrial or university laboratory. They proposed several forms of exotically treated rubbers, plastics and metals. On evaluation of the submissions, the prize was awarded to a little old lady – who crocheted a 'thimble' of string for the stick's ferrule. The string thimble fulfilled all the criteria Tom French summarised here. The old lady did not claim extensive research experience. Indeed, she claimed that, "*Everyone knows it works!*"

8. TRACTION – GETTING TO GRIPS WITH THE ROAD

The frictional forces acting at – and only at – the contact patch which drive a m/c forward during acceleration or slow it during braking depend on myriad factors. Material, speed, loading, temperature, wear, surface conditions, weather, and so on. These all come together to give, during each moment, a certain amount of 'grip'. Be that large or small, there is one Law that *always* holds. There is only *so much* grip – and not a tad more! It doesn't matter whether a bit is used for braking and/or another bit for turning. Independently of the direction it is used, the total remains constant. That being the case, it is common to represent this with a 'circle of forces' – as in Figure 14.

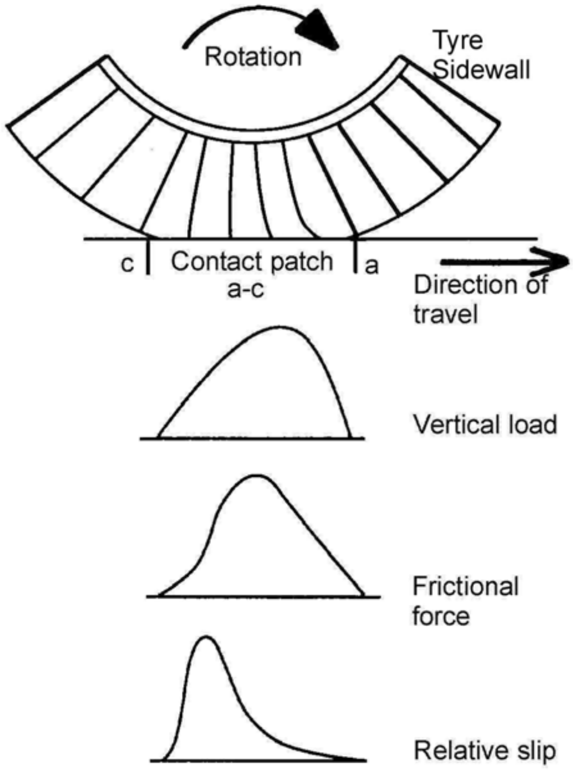
FIGURE 14: CIRCLE OF FORCES FOR ACCELERATION, BRAKING & TURNING



The *maximal* amount of frictional force is represented by the radius of the circle – it can *never* go beyond the circumference. Circle A shows the case when *all* the available force is used for acceleration. A little tap to the side of the tyre would cause it to slip sideways. Circle B shows every last ounce of force being used for braking. Again, none would be left for any sideways movements. Using the entire lateral grip that a tyre can deliver, as in C and D, leaves not a shred of grip in the tyre for acceleration or braking. Circle E shows a tyre accelerating out of a curve using maximal grip – as seen often in races. *R* represents the overall direction and the maximum available. *R* can be split into its forward (F_y) and sideways (F_x) components. Neither is maximal, but their resultant combination as R is. If the rider on the limit twitches the throttle by a hair's breadth –

so claiming grip for drive – this will be taken from the lateral grip. The tyre will break away. If he/she keeps the speed steady but has to tighten up the turn, there is no grip left to deal with the extra lateral forces. The tyre will break away.[17]

FIGURE 15: THE DEVELOPMENT OF TRACTION AT THE CONTACT PATCH



These possibilities all seem a little treacherous, yet they are in the hands of the rider. Other traps are more vicious in that only a detailed road-reading and razor-sharp reflexes can prevent mishaps. Remember Equation 2? It said that frictional force $F = \mu \ x \ W$, where μ is the *momentary* coefficient of friction between the tyre and the road and W is the *momentary* tyre loading. The surface of the road has become only a fraction less grippy – the rider on the limit doesn't have to do anything provocative – but that 'circle of forces' shrinks because the maximal Fx and/or Fy are less. The same would happen if the suspension unloaded on hitting a bump. Less W means less frictional force – a.k.a. less grip. Yet further misfortune can be interpreted from Fig. 13. The rider may be holding the tyre right on the peak of grip through a turn with just the right slip angle – the angle between the tyre and the direction of travel. A bump in the road that knocks the wheel to one side or the other – off that peak – could get the tyre sliding away. All of these can happen to the best of experts – experts who have exquisite control of the throttle, brakes and m/c attitude through a corner. We all can see what occasionally happens to them during GPs.

Because some road riders believe that they are experts, these factors are worth high-lighting in a summary. A road rider (male!) *could* ride on the limits of traction if, for *every* split second of the ride, he has a) *total* control of his throttle; b) *total* control of his braking; c) *total* control of his weight positioning, together with d) *total* awareness of the weight the suspension is keeping on the road, e) *total* awareness of the friction available on every inch of surface his tyres pass over; f) *total* awareness of the friction available on every inch of surface his tyres are about to pass over; g) *total* knowledge of

[17] Recalling Chapter 3, it is clear that Circle A is most relevant for the rear tyre where acceleration forces are transferred, whereas Circle B mostly refers to the front contact patch – that is, if the rider is braking correctly mostly with the front brake! The forward weight transfer caused by any slowing unloads the rear tyre. So, with $F = \mu \ x$ *(a much reduced W)*, that circle of forces of available grip at the rear shrinks to virtually nothing and *any* excessive demand for grip – forwards or backwards (F_Y), right or left (F_X) – will cause the rear to break away.

the road camber; h) *total* knowledge of geometry of every curve and i) *total* knowledge of what other road users may do, even when they don't know that themselves.

However, let us stay with mere mortals. The subjects of adhesion and slippage lead to the issue of how tractive forces – final drive and braking – get the m/c moving and stopping at all. Figure 15 provides a start for illustrating this. It shows the contact patch of the rotating drive wheel (*a-c*, as also in Fig. 4). We noted earlier that the distance of the chord *a-c* is marginally less than the arc around the circumference followed by tread not compressed into the contact patch. So, in going from *a* to *c* the tread has to slow down as the drive wheel carries on at the same speed. Because of the elastic nature of the tyre carcass the side walls stretch a little as the patch tends to get 'left behind' by the wheel. This creates a tension, as schematically shown by the force lines on the side wall. We also saw that the vertical loading of the tyre peaks at the pneumatic trail pivot, so the frictional force ($F = \mu x W$) is peaking about there as well. Further back along the contact patch – towards *c* – the local load on the tyre begins to diminish – leading to a drop in the frictional force. Coming out of the contact patch the tread then starts expanding and moving faster, so that its speed matches that of the circumference – as it must. With the tyre loading falling to zero, the frictional force also falls to zero.

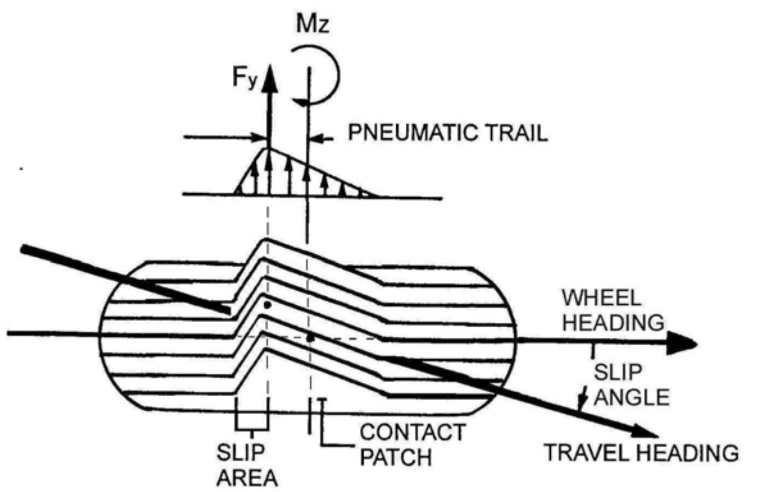
This process is somewhat like a climber clawing his way up a rope. His leading hand is like the leading edge of the tyre – gripping the rope as the tyre grips the road. His muscles (the drive forces) contract (compress) and draw his body forward (propels the vehicle). He makes this a continuous, flowing (circular) movement by bringing his other, trailing arm (the trailing edge of the tyre) over and forward. This now becomes the leading hand and his forward motion continues. So, the drive forces do not push the vehicle along. Through the contact patch they haul it along. The processes in braking are similar, except that the 'drive' is negative, with the drive wheel running slower than the contact patch. Therefore it is not the brakes that stop the vehicle. They just slow the wheel down. The real stopping is done by the contact patch clawing its way backwards. (It may seem a trivial point, but serves as a reminder that no matter how superb a *brake* system is in slowing the *wheel*, it may be ineffective if the *tyre* system is not right.)

There is one difference between a tyre and a climber. If a climber's hand slips, he loses power and can't climb as efficiently. With the tread, though, there is always a little slippage. It reaches its maximum just after the 'pneumatic pivot' where the vertical load peaks – and when the compressed rubber is *just* beginning to relax. Because it is a matter of indifference to a tyre as to whether it is transmitting drive or braking forces, Fig. 13 is again relevant here (with the '100% locked wheel' in the braking situation changed to '100% spinning' for the drive situation.) There is no slippage – and so no frictional force – involved when the wheel is rolling free. As soon as forces are applied to the wheel – drive or braking – the tyre tread and wheel start moving at different speeds. With forward drive the wheel is getting fractionally ahead of the contact patch, with braking it hangs back. This causes minute amounts of slippage in parts of the contact patch. The '100%' situation is when the whole contact patch is slipping – when the wheel forces are just too great to be held in check by the frictional forces of the patch. This we know as a skid.

9. TURNING

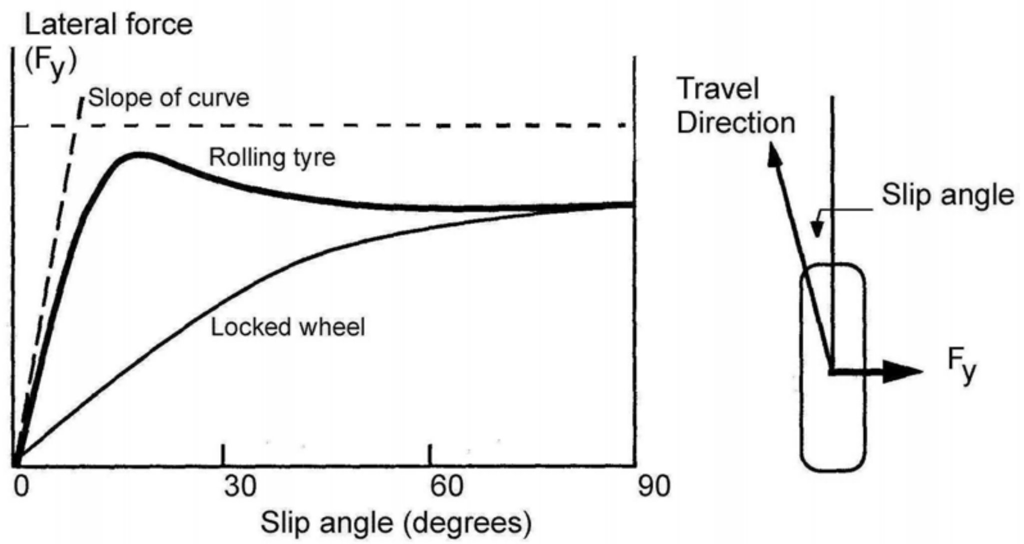
For vehicles following a curved path it is first necessary to consider the situation when the steered wheels are turned in the desired direction. This is the way cars are steered – and m/cs at low speed. The events at the contact patch are illustrated in Figure 16.

FIGURE 16: CONTACT PATCH DEFORMATION AND LATERAL FORCES



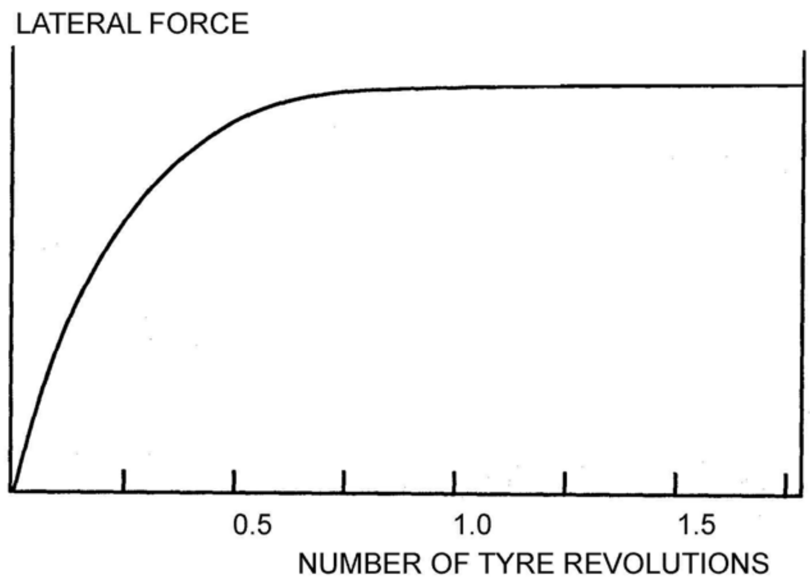
Here the steered wheel is turned to the left, away from the travel heading. As the tread makes its first contact with the road, it does not deflect initially, so no lateral force is generated. As it continues in its direction of travel and pushes into the contact patch, the elements of the tread continue to grip their original contact point with the road surface – and so end up to the side in respect to the body of the tyre. As those elements move back through the contact patch the lateral forces increase to a point where it overcomes the available local friction to cause slippage.

FIGURE 17: LATERAL FORCE AT VARIOUS SLIP ANGLES



The amount of friction available laterally is variable and depends on the slip angle, as shown in Figure 17. Obviously with a zero slip angle at the steering pivot (M_z) – when the tyres are rolling true in the direction of travel – there is zero lateral force. As the angle of the wheels is turned more and more away from the direction of travel – so increasing the slip angle, the amount of lateral frictional force available (F_y) climbs rapidly. (The rate at which this climbs towards its peak clearly influences the 'feel' of the steering. Measured as the slope of the slip angle/lateral-force curve at its origin, it is called the cornering stiffness, Cα.) This force peaks behind the steering pivot, giving rise to the *pneumatic trail*. As seen before (Fig. 12), the lateral force reaches its maximum with slip angles of 10°-20°. (In principle this could approach the maximum possible, $\mu_{PEAK}\ x\ W$, the peak coefficient of friction times the weight on the tyre.[18]) It is this lateral force which pulls the vehicle into a curved path. It is this necessary slippage causing most wear on the tyre. (So, two riders comparing tyre wear need to know if one or both ride mostly on straight or twisty roads.)

FIGURE 18: DEVELOPMENT OF LATERAL FORCE DURING TYRE ROTATION



[18] Dependant on the detailed scientific analysis called for, a coefficient of friction (μ) can be measured in various situations. This gives giving several different values. The first one listed is the most relevant – and the one usually just called 'the' coefficient of friction.
BRAKING TRACTION COEFFICIENT is the maximum value obtained when braking, without locking the wheel, in the specified conditions of surface, environment and operating conditions.
DRIVING TRACTION COEFFICIENT is the maximal value when driving the wheel, without spinning the wheel, in the specified conditions.
LATERAL TRACTION COEFFICIENT is the maximal value obtained when applying lateral forces to a free-rolling wheel, in the specified conditions.
SLIDING BRAKING TRACTION COEFFICIENT is the maximal value obtained with a locked wheel, in the specified conditions.

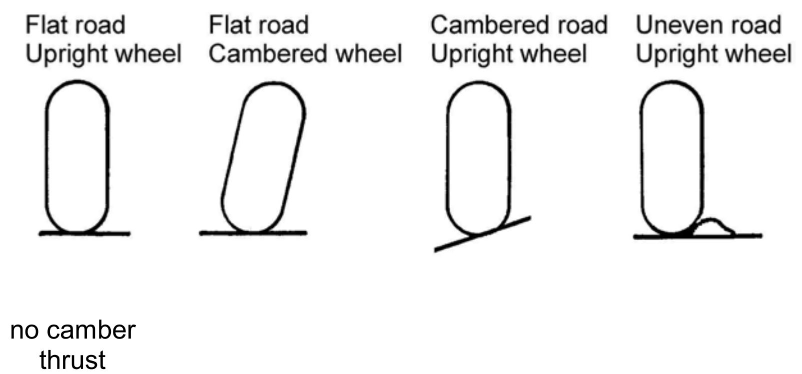
When the slip angle is greater than zero a self-alignment force is created, with a turning couple (M_z, Fig. 16) around the pneumatic trail's pivotal point. It tries to pull the tyre back in line from the travel heading towards the wheel heading. However, with the steering handlebar/wheel the driver/rider holds the heading of the rolling wheels steady – an easy task requiring only finger-tip pressure because of the gearing of the steering mechanism. With the tyre gripping the road, the only part of the system with some freedom to move is the vehicle. So, instead of the self-aligning force pulling the wheels more into line with the vehicle, the vehicle is pulled more into line with the wheels. The vehicle follows a curved path.[19]

So here are several factors influencing not only the practical contribution of a tyre to steering but also the ways in which these feed back to the driver or rider. The way the tread deformation develops, the way friction changes with slip angle, the relative location of the pneumatic trail and the way that develops, all affect the feel of the steering. Even speed factors play a role, as illustrated in Figure 18.

It shows that a step twist of the steering does not produce the lateral force immediately. We noted above that the deformation induced by the slip angle has to feed into the contact patch. So, the tyre has to 'turn into' the road for half to one full revolution before the lateral force peaks. Obviously the feel of this would be most noticeable at slow speeds. Consider a tyre with a circumference of about 2 metres – one needing a full revolution to develop the full lateral forces for turning. At about 16 kph (10 mph) it would take about half a second for the steering to develop its 'steady-state' level of lateral turning forces. You would have to be a rather insensitive driver not to be aware of this slow response. On a m/c, the momentary counter-steering push to get the machine leaning over (a push right to lean left, a left push to lean right) relies on the shift of the pneumatic trail. Clearly, the responsiveness of the tyre will be one of the factors determining the 'flickability' of the m/c through a curve – and particularly through a series of curves where the pneumatic trail on one side of the centre-line has to relax and develop on the other.

So, after saying earlier that this process of developing lateral turning forces through the slip angle applies mostly to two-track vehicle such as cars and trucks, we come back to single tracked m/cs. The main force allowing a single-track vehicle, such as a m/c, to turn is *camber thrust*.

FIGURE 19: SITUATIONS PRODUCING LATERAL CAMBER THRUST

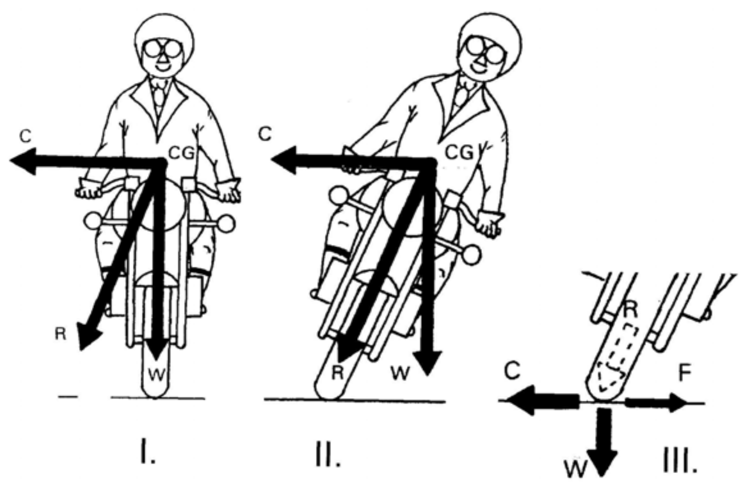


[19] That finger-tip pressure only has to be relaxed on a car steering wheel to feel the self-aligning force pulling the wheels back into line. Some bad drivers cultivate the habit to make the wheels 'snap' back into place.

Now, camber is usually encountered when talking about the sloping cross-section of a road, where normally the road slopes down from its centre to its edge. Here, the vertical line of the vehicle and the road surface are not at 90°. However, as far as the physics are concerned it doesn't matter whether the road slants or the vehicle leans, camber thrust is still developed, as it is when the side of the tread strikes a surface irregularity. These situations are illustrated in Figure 19.

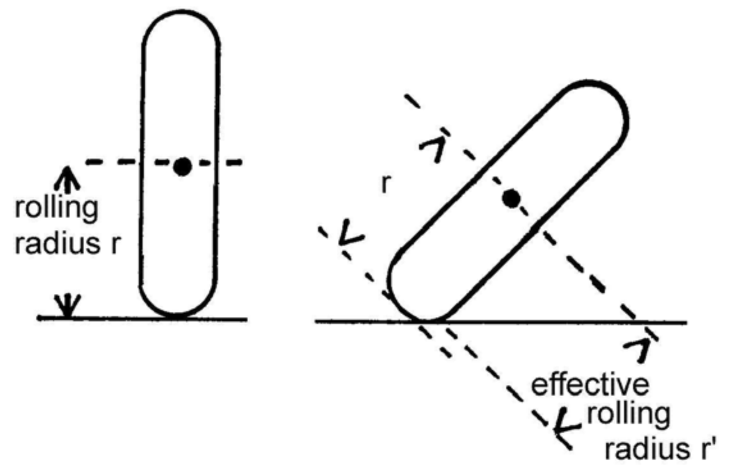
Indeed, looking at photographs of old racing cars shows some with marked camber in their suspension set-up, with wheels leaning in quite noticeably. This means that wheels on the inside of a curve and which carry most of the displaced weight, would become more vertical in the curve. This would leave more of the central part of the tread in contact with the road. Rather than suggesting this revealed inadequacies of the tread outside and/or side walls of those early and narrow tyres, one can say it was device for getting grip where needed in a curve.

FIGURE 20: THE BALANCING OF SIDE FORCES BY LEANING A SINGLE TRACK VEHICLE



Although this is not an essay on the physics of m/c riding, a brief review will show how what forces act on the contact patch when the m/c leans and follows a curved path. Figure 20 shows some basics. When the m/c is upright, as in Fig. 20/I, the weight (W) acting from the centre of gravity projects downwards, through the contact patch. There are no forces trying to tip it over. Then a side-force, C, starts acting. This could be caused by a side-wind or it could be centrifugal force. This would arise if the rider tried to steer around a curve – and stay upright, as in a car! A force acting one way (W) and another acting in a different direction (C) always function as an algebraic sum of the two, in a direction somewhere between the pair. This resultant, R, is also shown in Fig. 20/I. This is acting outside the pivot point of the contact patch – and threatens to overturn the m/c towards the outside of the curve (or to blow the rider over if a wind had caused the side-force.) The only way to prevent this is to get that force, R, acting through the contact patch again – to eliminate the turning couple that threatens stability. The rider *has* to lean, as shown in Fig. 20/II. Although theoretically the forces are acting at the centre of gravity (CG), they express themselves in practical terms at the contact patch. Although it is the resultant force R that acts there, its original component parts, W and C, are still there – as seen in Fig. 20/III. So there is the weight W pressing on the road and the centrifugal force, C, trying to pull the tyre away. This will be resisted so long as the frictional force (F) between tyre and road is greater. (It is again recalled that $F = \mu$ *x* W, where μ is the coefficient of friction – which only exceptionally surpasses 1.0 and is usually way below 1.0. Remember also the 'friction circle'. The available friction is used both in resisting lateral forces and in providing either drive or braking. The one can only use what is 'left over' by the other.)

FIGURE 21: EFFECT OF LEAN ON THE TYRE ROLLING RADIUS



Another factor to remember is the cross-sectional shape of a m/c tyre. Because the m/c has to lean, the tread can't have the squarish cross-section of a four-wheeler. It is rounded. That has consequences for the construction and, when riding on the limits, for the behaviour of the m/c. In Figure 21 one consequence is shown. (The illustration is simplified by ignoring the tyre deformation.) In the vertical position, the m/c tyre has its rolling radius (*r*) as shown on the left of Fig. 21. Leaned over, though, the tyre turns on an area up the rounded cross-section of the tread. This shortens the effective radius between the axle and pivot to *r'*. In essence, this lowers the gearing ratio by a factor of *(r/r')*. This may seem to be more relevant to a rider on the limits but it *could* be felt by a normal rider.

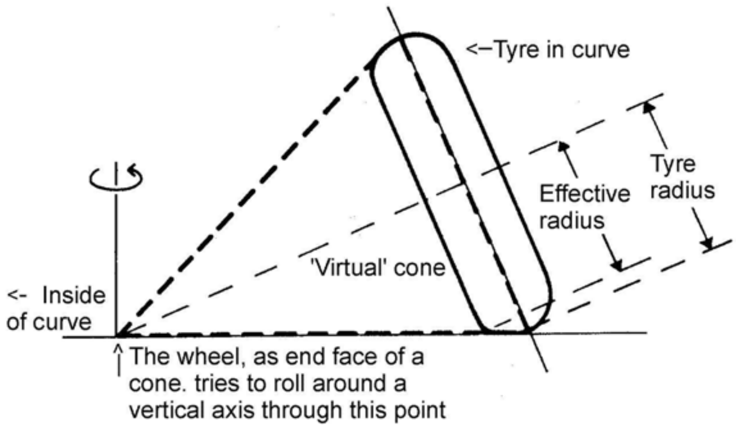
When entering and following a curve, it is important to keep a slightly positive throttle on – to maintain a constant speed. Consider what happens if a rider enters a curve with a trailing throttle. The moment the bike is leant into the corner the gearing drops – so does the speed. As the curve speed drops, so does the centrifugal force. The rider is now leant over too much and the m/c weight causes the bike to drop into the corner. Add to this the fact that the slowing causes the m/c's weight to move forward – and disturb the suspension. This is usually called 'getting out of shape'. If the rider is slow in reacting or if there is too much play in the throttle for it to be taken up instantly, the rider may crash because the speed can't be recovered soon enough. This is particularly problematic when navigating tight uphill hairpin bends slowly. The m/c might be just at that critical speed between the need for direct steering (at slow speeds) – using tyre patch slippage to steer – and leaning (at higher speeds) when camber thrust takes over. At best the m/c gets all out of shape, but the rider survives. At worst ... !

To realise another consequence of m/cs needing to lean in a curve, stand up with your legs straight and your feet about 15 cm (6 in) apart – somewhat like the vertical tyre walls on the left of Fig. 21. Now lean over to one side – as far as you can without toppling over – just like the right-hand illustration of Fig. 21. How long can you hold that position before your leg buckles under? How long can one leg support virtually your whole weight? That is the situation facing the side walls of that tyre banked over in Fig. 21. Contrary to the situation with a car tyre that supports most of the weight on two side walls for much of the time, a m/c tyre supports it only on one in curves. This means that the side wall construction for a m/c tyre has to be that much stronger than for a car tyre. Here a balance has to be found between two side-walls flexible enough to provide the spring action described earlier yet strong enough alone to support the additional weight imposed in a curve. Changing tyre to ones with a different side wall strength may affect the cornering behaviour of the m/c.

FIGURE 22: AN ICE-CREAM CONE!

Earlier, the mechanism taking a car around a curve was described – slippage of the contact patch deformed to the side of the centre-line. So, although it was shown that a single track vehicle like a m/c must lean to follow a curved path, the physics of why the camber thrust that develops should take a m/c around a curve still needs to be explained. Take a look at Figure 22 – a chocolate chip ice-cream cone. Imagine that the chocolate-studded disc is a m/c tyre. (After all it has a similar form and, with the cone resting on the table, the disc is leaned over.) Imagine putting your finger on top of the chocolate and pushing – of supplying some drive to your chocolate 'tyre. How does the ice-cream move? It rolls around the point of the cone.

FIGURE 23: THE VIRTUAL CONE PRODUCED BY THE TYRE AND THE TURNING FORCES



But hold on, you might say, a m/c tyre does not have a biscuit cone sticking on its sides, so what is there for it to run around? The answer to this is that the physical nature of the cone is not important. The cone just carries the forces. It is these that form the cone. For the tyre this is a 'virtual' cone, as shown in Figure 23.

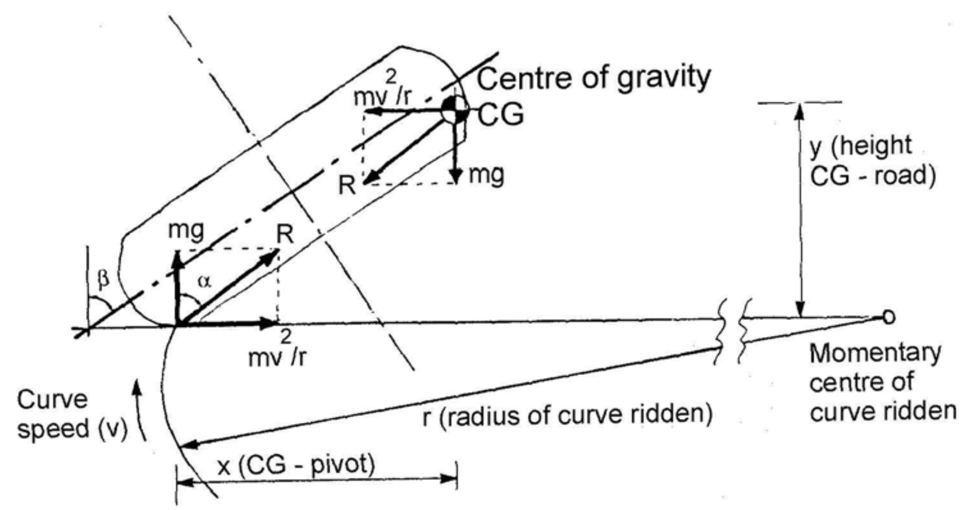
The wheel forms the circular base and the axle its centre. The m/c tries to turn a circle around the vertical plane where the axle projects to the road. Without any other forces acting, this would have a radius of about ½ metre (1½ ft), causing all sorts of mayhem as footrests and/or engine covers scraped the tarmac. However, the traction forces and momentum drive it in a much wider circle, so that the forces involved and the virtual cone they produce look more like the situation shown in Figure 24. Although everything starts out with what is happening to the centre of gravity (CG), this allows us to say something about what is happening at the contact patch.

At CG, the centrifugal force (mv^2/r, where m is the mass of the m/c) is trying to throw the m/c to the outside of the curve. The turning couple (leverage) it creates about the pivot (the contact patch) is $m.v^2/r$ times y. To counteract this, the m/c is leant to the inside of the curve, so that its own weight, W (where $W = mg$, with g being the constant due to gravity, 9.81 m/s^2), can act as a counter-leverage. This counter-couple will be mg times x. When the m/c is in a steady state around the curve, these two couples must be equal, so $y.m.v^2/r$ must equal $x.m.g$. Written another way (which eliminates m, the weight factor):

$$x/y = v^2/g.r \qquad \text{(Equation 4)}$$

Obviously x and y are defined by the position of the centre of gravity, that is, by the geometry of the m/c and rider. It is this that determines the necessary angle of lean. The actual weight of the m/c does not come into the equation. So, if the CG's of a 180 kg sports m/c and a 500 kg tourer are at the same height (y is the same for each m/c) they lean the same amount (making each x the same) to pass the same corner (with radius r) at the same speed (v).

FIGURE 24: THE FORCES ACTING ON A TURNING MOTORCYCLE



The forces acting on CG also act at the contact with the road, following Newton's Laws that say that for every force there is an equal and opposite reaction. So, with the contact patch weighing down on the road with a weight of mg, the road must be pushing back with a force of mg (or the m/c would disappear towards the centre of the Earth!) If the centrifugal force is trying to pull the tyre out with a force of $m.v^2/r$ then, if the m/c does not slide, the friction of the tyre must be preventing this with a force of $m.v^2/r$. This allows us, out of curiosity, to make actual calculations of just some of the forces the tyre has to bear, day in, day out, mile after mile.

Take a dry country road of a reasonable surface with a reasonably good coefficient of friction (μ) of 0.8 along which a loaded Gold Wing is travelling. The whole rig weighs 500 kg. A medium-sized roundabout is reached. It has a radius of 35 metres (115 ft). The rider does the necessary braking beforehand, so that the suspension is stable and, let us say, is evenly distributed 50:50 fore and aft (just like the unloaded m/c) to load each wheel with 250 kg. The rider maintains a speed of 60 kph (37.3 mph) and circumnavigates the roundabout 1 metre (33 ft) from the inside edge. The frictional force (F) balancing out the centrifugal force, $m.v^2/r$, is 196.6 kg. The maximal friction available is $\mu \ x \ W$, or 200 kg. So the contact patch has that enormous lateral force acting upon it – and, making a further calculation, the m/c must lean 38° to get around the roundabout at that speed.

How much reserve does the rider have? Well, going back to that circle of forces – the frictional forces – if 196.6 kg of friction are being used to get around the corner, then there is only 3.4 kg left for drive. The rider only has to twitch the throttle open and he exceeds the available friction. The tyre will slide. What if the rider is a fraction faster – and by a fraction let us talk about ¾ kph (½ mph) and can't change his line because he has gone inside a large truck on the roundabout? Of the available 200 kg of friction he now needs 201.6 kg. Oops! The tyre just hasn't got that in it. He slides gracefully outwards, towards the truck – maybe under one of its 18 wheels. Such a scenario doesn't bear thinking about. Take it that the rider did not exceed his reserves and did indeed get round safely. Confident in his skills of riding on the limit he enters the roundabout the same way on his way back. This time, however, the surface on the other side of the roundabout is a *minimally* more polished – so that μ is fractionally reduced to 0.78. With the rider still needing 196.6 kg of 'grip', the contact patch only offers 195 kg. Oops![20] Again not enough.

This illustrates other aspects of riding on the limits – in respect to both loading and turning. It was noted that the m/c weight (W) is irrelevant. The frictional force demanded (F_D) is given by $W.v^2/g.r$. Frictional force available from the tyre (F_A) is given by $W.\mu$. So, assuming that the weight stays constant, F_D is affected by the speed through the turn, as we have seen, and the radius of the curve ridden. Also as we have seen, F_A is determined by the coefficient of friction between the contact patch and the road surface. But what if the weight *does* change?

With the 'circle of forces' we saw that only so much friction is available. Any change in drive that calls on additional grip – accelerating, braking, turning more tightly – may take the tyre out of the friction circle and cause the tyre to wash out. However, a secondary affect may come from the shift in weight that occurs – or doesn't occur, as the case may be. Take the case of accelerating out of a curve. Assume that the rear tyre

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[20] Do not imagine that a sports m/c rider would fare any better. The factor of weight cancels out in the various calculations. So, imagine for a moment that a 180 kg sports m/c, with an 80 kg rider is running on tyres identical to those of the Gold Wing loaded up to 250 kg per tyre. Also with a 50:50 weight distribution, there are 130 kg on each tyre of the sports m/c. All the above figures will be modified by a factor of 130/250. In the first, safely negotiated situation, the curve forces would demand 102.3 kg of frictional force. The tyres could deliver 104 kg. So again the rider would be safe – just – with 1.7 kg of reserve. However, in absolute terms the rider of the lighter sports m/c actually has a smaller reserve.

has enough traction reserve to provide the additional demands. So *v*, the speed of both the rear and the front wheels increases. This increases the centrifugal force – which needs more grip to counteract it. As the m/c accelerates the rear squats and the front lifts as the weight redistributes itself. So, still in the curve, the poor front tyre needs more grip to deal with the increased curve speed. Unfortunately, though, the lightening of the front end reduces the total available friction. It washes out. A parallel situation occurs when braking in a curve where the tyre might be able to take the additional demand for braking grip – if only the weight did not unload from the rear tyre.

Just in passing, a loaded m/c was used in the above calculations. It was assumed that it was loaded well to give a weight distribution of 50:50. What if the loaded m/c was badly loaded with a 40:60 front-rear distribution, maybe compounded by 10 kg of trailer tongue weight hitched as far back as it can be to apply maximal unloading of the front wheel. To and from work that rider may have run the roundabout twice a day all year long – as constant as Valentino Rossi in his curve speeds[21] – but with the unloaded 50:50 m/c. He runs that roundabout as always, but with that unevenly loaded m/c. Oops! That holiday didn't last long.

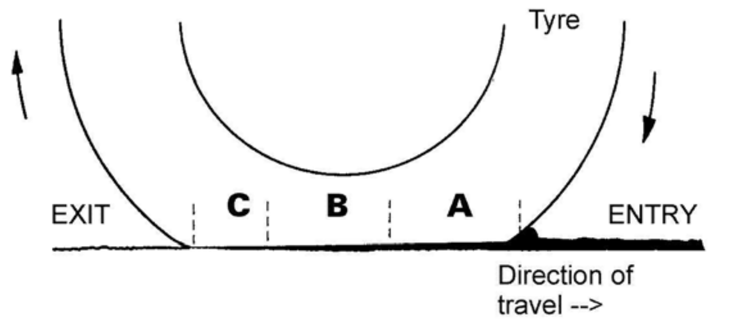
[21] Talking of Valentino Rossi, there is an addition to that earlier footnote about the various coefficients of friction that can be measured. Clearly they can be measured because they come into play. O.K., only one of them is relevant for the normal road rider. Power-sliding around a curve, the likes of Valentino are juggling with the grip (or lack of it) that results from these frictions – on a time-scale that can be measured in milliseconds. Consideration of this also leads to an explanation of that phenomenon we often see on the race-track – high-siding. Looking back to Fig. 17 will help. Going into the curve, the racer spins the rear wheel and with the throttle, delicately balances the forward and lateral grip to make the m/c come around more quickly. The slip angle between the direction the wheel points and the direction the m/c moves is large. So, from Fig. 17, the tyre is to the right of that peak value of lateral grip. Coming out of the curve the rider *starts* to lift the m/c, straighten it out and give gas. This reduces the slip angle of the spinning, sliding rear wheel – although the m/c may still not be upright. Now the tyre may no longer find itself to the right of that peak traction point, but on it! Now there is enough grip on it not only to stop the slide but – remembering the friction circle – there is grip to spare for that forward drive as the rider gives gas. The tyre bites and jumps forward. This acceleration is virtually instantaneous – as is the increase in centrifugal force of the m/c still in the tail-end of the curve. This force whips the m/c up – and maybe over to the outside of the curve. No rider can withstand the enormity of the force involved and he is spat over the 'high-side' of the machine.

10. TYRE TREAD

In a perfect world there would be no tread patterns on m/c tyres. We would ride around on ‘slicks’ because, in that perfect world, it would not rain. Unfortunately the world is far from perfect, particularly in respect to the occasional (!) shower of rain. Even though there are heavenly moments of dry weather and in spite of many a sporting aspiration, The Law *never* allows us to ride around on slicks. It doesn’t seem to trust us, like true racing riders, to throw our hands in the air the moment a few drops fall and *immediately* pull into the pits to change to treaded rain tyres. It demands not just some tread but a minimal amount of tread. It seems that The Law doesn’t appreciate us killing ourselves. (This is one occasion where I agree wholeheartedly with The Law.)

It is not that rain in itself causes problems. It is enough for roads just to be wet. Some old U.K. data show that about 14% of accidents on dry roads involved skidding. When the roads were wet that figure went up to 35%. Further old weather data showed that U.K. roads remained wet for about 5 times longer than the time rain had been falling. (Researchers explore these factors using a 1 mm (1/25th inch) water film to simulate ‘wet’ roads and a 2.5 mm (1/10th inch) for ‘flooded’ roads.[22]) So, the effects of water can be prolonged. Its effects are best understood by seeing three zones in the contact patch, as proposed by V.E. Gough and shown in Figure 25.

FIGURE 25: THE THREE STAGES OF WATER UNDER A ROLLING TYRE



ZONE A – as the tyre enters a stationary film of water it can displace some water to the sides. However, as we have seen before, the tyre is not yet applying much pressure on the road. Therefore the water film remains unbroken – and the coefficient of friction is virtually zero.

ZONE B – by now the water film is being broken down as the full weight acting on the tyre comes into play. Its thickness might be only a thousandth of a millimetre or so – or it still might be thicker. Therefore the coefficient of friction will vary wildly in this local area. It could still be very low or it could reach almost dry-road levels.

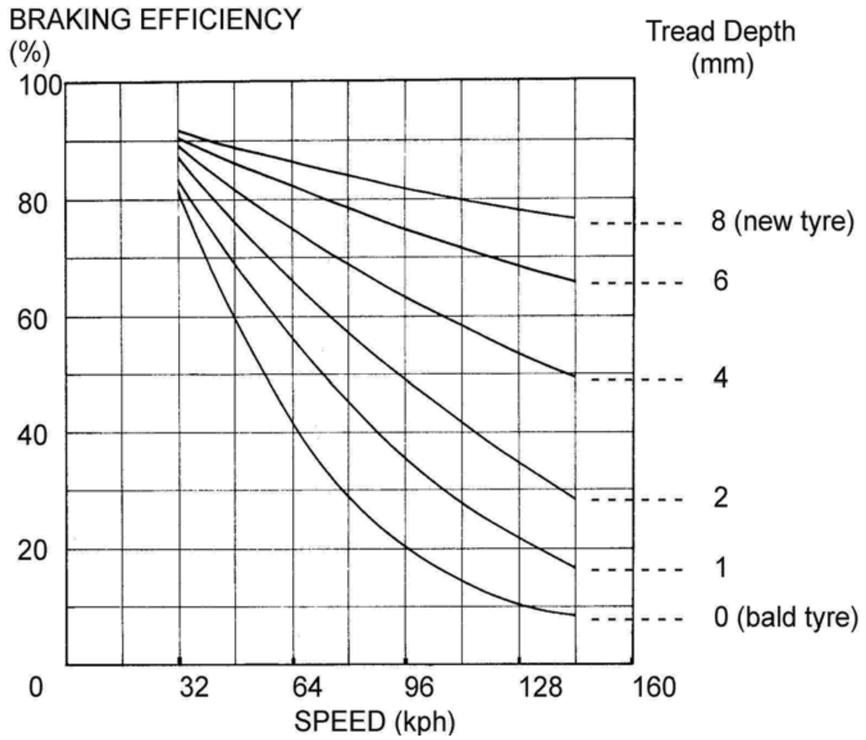
ZONE C – here, to all intents and purposes, the film of water has been removed. Tyre and road are mating closely – dry-road friction levels are available. So, of the entire contact patch, this Zone C area is providing most of the adhesion. The purpose of tread design for road m/cs is to advance and extend Zone C into B and if possible, B into A.

Even when the tyre is good at ejecting water under it, there is always a time factor involved. Although a tyre will sink through a 2.5 mm (1/10th inch) film of water quite

[22] Most research was on car tyres. However, most basic principles apply to both car and m/c tyres.

quickly to a thickness of 0.5 mm – in about 1 msec – the rate slows dramatically so that the water film is still 0.1 mm thick after 6 msec. The faster a wheel is turning, the less time there is for the tyre to get past Zones A and B. Consider a tyre with the dimensions of a Gold Wing tyre – 2 metre circumference and a contact patch 15 cm long. At 96 kph (60 mph) the *whole* contact patch stays in contact with the road for only 5.6 msec. Not much time to squeeze out the surface water! Obviously, then, the speed at which a m/c travels over wet roads influences the available traction. So, aquaplaning is not just a question of a wave of water building up at the leading edge of the tyre – and the tyre climbing off the road and on to this. It is the very thin layers of water underneath the rear part of the contact patch that destroy the traction. At best, this lowers steering and braking forces. Albeit for a car tyre, Figure 26 shows the effect of speed on braking efficiency when running through 1 mm of water at speeds up to 144 kph (90 mph).

FIGURE 26: BRAKING EFFICIENCY AND TREAD DEPTH FOR A CAR TYRE RUNNING IN 1 mm OF SURFACE WATER



At low speed, braking efficiency is not perfect (80-92%) and treadless tyres are nearly as efficient as new ones. This is because the contact patch has time to sink through the film of water. The braking efficiency of a new tyre is impaired at 144 kph – sinking to about 77% of the maximal possible. (The strident recommendations to reduce speed when riding/driving in the wet are not just because of the risk of aquaplaning even with new tyres. The data above were obtained with master-brakers. Few of us are that!) However, as the tread wears, wet braking efficiency drops dramatically, so that at speed a bald tyre has no braking efficiency to speak of. This is why The Law demands that we have some minimal depth of tread. Yet even the most widespread European legal demand (1.6 mm) is extremely modest – because, extrapolating to these curves to a tyre with 1.6 mm of tread running at highway speeds (110 kph, 70 mph) only has about 30% of the possible braking efficiency available.[23]

These data come from studies on 1 mm of water. The situation worsens dramatically on a 'flooded' road (defined in the scientific studies as 2.5 mm of water). Already at 80 kph (50 mph) a new tyre has only 70% of braking efficiency. One at the legal minimal tread depth (1.6 mm) is down to 30%. At a highway speed (110 kph, 70 mph) the new tyre efficiency is just over half of the 100% level. The minimally legal tyre? Well, let's say that you can probably slow the vehicle better by sticking your hand in the wind! Seriously, though, if a m/c had brakes so defective that they only braked to 1/3rd of their efficiency, would you ride it on busy public roads? It would be no different to riding a bike with 100% efficient brakes but tyres only 30% efficient.

FIGURE 27: MICHELIN C68 MOTOCROSS TYRE

So, the *primary* purpose of tread profile on a *road-going* tyre is not to provide grip. It is to get rid of the underlying water that takes away grip. Given other design constraints, it should do this as effectively as possible, so that the rubber and road-surface can do what they are supposed to do – that is, grip one another. One would think that science had revealed particular ways – limited in number – by which a rolling tyre could eject this surface water. However, looking around at the tyres and the varieties of tread pattern available could suggest that the choice is more a black art than a science. Science certainly has made enormous progress in understanding the design needs but that earlier crucial phrase mentioned earlier – *given other design constraints* – comes into the equations. Perhaps an examination of these factors should start by considering Fig. 26 again and a tyre that is useless on wet roads, as illustrated in Figure 27.

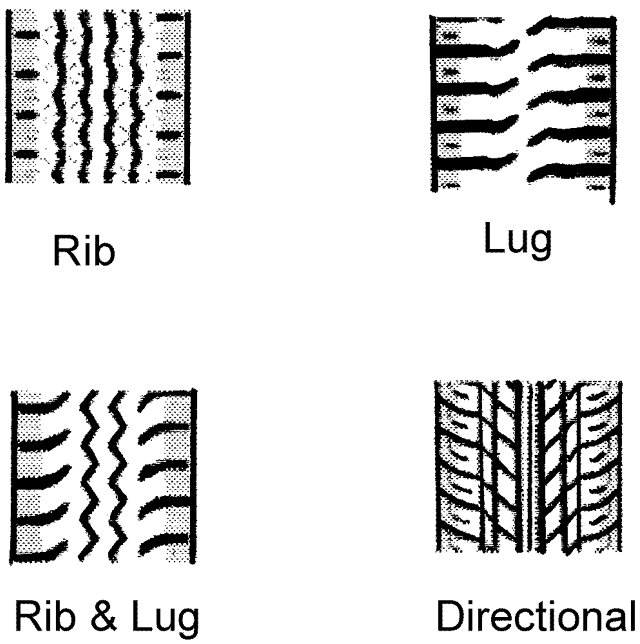
The evidence for wet braking efficiency in Fig. 26 suggests that the tread profile depth should be as great as possible for a road-going tyre. This should give the best braking at speed and, also, the most rubber to wear before efficiency falls. Whatever its pattern, however, the tread profile is only laid down on top of the tyre carcass. It does not contain the supporting cords and belts. It is just rubber. The 'taller' it is, the less firm it is under braking, accelerating and turning stresses. Too much tread therefore makes

[23] I couldn't find Federal tread depth limits for USA. However, Bridgestone-Firestone advise US riders that: "When the tyre is worn to the built-in indicators at 1/32nd inch (0.8 mm) or less tread groove depth, or the tyre cord or fabric is exposed, the tire is dangerously worn and must be replaced immediately." This I find unbelievable and unacceptable advice – because to a lay person it implies that so long as cords, etc. are *not* exposed or there is more than 0.8 mm of tread depth available (what about 0.85 mm?) then the tyre is not dangerously worn.

handling uncertain as the rubber deforms, twists and squirms. There is another problem with thick treads. Their instability increases rolling resistance. Power is lost in deforming the rubber rather than in driving the vehicle. However, the good news is that a 50% tread wear can lower rolling resistance by 20%. That could make a noticeable effect on fuel consumption. If so, the wise rider would put the saved fuel money aside and replace the tyres before overly worn tyres killed him/her. You can't win, can you!

So, the depth of tread on a new tyre has to meet the compromise providing good grip, acceptable wear, satisfactory handling and reasonable rolling resistance as well as removing water. Nonetheless, there are tyres that are without that compromise, as shown in Fig. 27. The tread of this extreme, 'knobbly' tyre is not meant to remove water from a road surface. The wide, high blocks should bite into sand, mud or a loose surface, compact it together and provide traction. Just looking at the tread suggests that on a tarmac surface there would be more air in contact with the road than rubber. (Air has a notoriously poor coefficient of friction, as anyone falling off a cliff would testify.) True, there would be little possibility of road-surface water building up under such a tyre, but even in the wet there still has to be rubber in contact with the road. On a tarmac road the m/c would be 'on stilts', resting on a handful of high rubber blocks. These would lead to extremes of squirm during acceleration, braking and turning if anyone was foolish enough to run a motocross tyre on the highway. They could expect rapid failure due to heat generation. (Such 'dedicated purpose' tyres are usually marked 'Not for Road Use' on the side wall – for good reason.)

FIGURE 28: ELEMENTS OF TYRE TREAD DESIGNS



To be fair, the problem of tread squirm is not restricted to knobblies. Any groove in the tyre – even a road tyre – allows the rubber blocks to move. Grooving may allow water to escape. Rain water may contribute some cooling but the tread channels are not renowned for cooling, air-conditioning properties in the dry. The problem comes to the fore with racers on rain-tyres, only to have the conditions dry out. Because of the heat generated, the tyres go off *very* rapidly. (One con-solation for us having a very wet riding season is that the tyres would not have worn quite so much – assuming that we do indeed ride in all weathers!

So, already three design constraints have come up. Although tread depth is important for clearing water, (a bald tyre does not clear water), too deep a tread or widely spaced elements introduce new problems into the situation. A crude generalisation can suggest how these things affect tread design of different tyre applications. A sports m/c rider, out mainly for leisure, certainly doesn't want any tread squirm as he sweeps quickly through dry-road curves. This would be avoided with a minimally grooved tread, but that would wear very quickly. Further, the rider has to accept the compromise that such a tyre may not be the ultimate in the wet. A long-distance touring rider spends long days in the saddle, with a high probability of meeting all weather conditions. He does not wish to emulate GP riders. He does not enter the territory where tread squirm is an issue. He probably looks for total sure-footedness from his tyres in the wet. The expectations of these two riders could lead to different tread designs. Some basic tread patterns are shown in Figure 28. (They are car tyres, but the principles involved are the same for m/c tyres.) Each of them has certain advantages and/or disadvantages.

FIGURE 29: MICHELIN MACADAM FRONT & REAR TREAD PATTERNS

HONDA GL1100 FRONT — HONDA GL1100 REAR

The ribbed pattern dates from earliest times. Its rolling resistance is low and it provides good straight-line stability and steering control because of the lateral resistance it offers. A disadvantage is lower grip during acceleration and braking on wet roads. Lug patterns, however have good braking power and traction but tend to be noisy. Because of higher rolling resistance they are not so suitable for high speed riding that generates heat and uses fuel. As could be expected, a compromise is found in the rib and lug pattern. The central ribbing provides directional control and the *shoulder* lugs improve braking and driving efficiency. Other patterns become more complex and, because of the more complex construction moulds, correspondingly more costly. One such tread is the directional one. It may have multiple drainage ribs around the centre of the tread as well as connecting channels to each other and the outside edges. This ends up with treads made up of many blocks. The drainage channels for water are directional – obviously requiring the tyre to be mounted in its defined rolling direction. With optimised water removal, the directional tread offers good stability on wet roads but also generally good braking and drive performance. However, with the tread blocks being smaller, wear may be higher.

An obvious but often forgotten factor is that m/c tyres are usually specifically designed for front *or* rear use (a factor not present with car tyres). This is not just a question of tyre dimensions. The front tyre leads into the undisturbed water film. Its water-clearing properties are therefore paramount. Except in flooded conditions, the rear tyre is mostly running on road already partially cleared of water by the front tyre. Although both tyres take braking forces, the rear supplies the drive during acceleration. It follows that the tread patterns of front and rear tyres can differ. An example is shown in Figure 29.

The front tyre is directional, with two central channels, slightly waved to increase their effective capacity. These are connected directly to the outer edges with many directional lateral channels. The 'matching' directional rear tyre has a different design, with a more basic rib and lug pattern. The single central rib is virtually straight but is not linked to the lateral lugs. This leaves plenty of rubber in the centre of the tread to provide traction. Lateral channels sweep backwards for ejecting water. This tyre also has to be mounted with the correct rolling direction.

FIGURE 30: FRONT TYRES FROM DIFFERENT MANUFACTURERS

Michelin Commander (Honda GL 1200) | Metzeler Laser M33 (Honda CB750 K6)

To illustrate the various 'solutions' from different manufacturers, Figure 30 shows two front tyres. Although the more sporty, directional Metzeler has a centre groove, the emphasis is on the side channels. The touring Michelin has a broad, wavy channel in the centre but relatively fewer side channels. The Michelin also illustrates another design variation. Just visible on either side of the centre groove are small 'reservoirs'. With no outlet their purpose is just to catch and hold a little surface water until it can be spun out the back. However, the design of such reservoirs is not an easy matter. It would be no good if a reservoir carried water back into the contact patch, only to have it pumped out into Zone C (Fig. 25) by the changing rubber pressures. It would be an immediate lubricant for the tyre to slide. (Incidentally, although it is not diagnostic, the band of light coloration around the centre of the Michelin tyre suggests that it has been running over-inflated.)

All factors here – the size of the channels, their number, distribution, direction and the amount of rubber in contact with the road are carefully designed to give particular water-clearing and traction properties.[24] Central to the design specification is the contact patch – defined by the inflation pressure. This again emphasises the need for inflation pressures to be correct if the traction and water-clearance are to be optimal.

[24] The ratio of the area of grooves (void of rubber) to the total area of tread in contact with the road is the 'void ratio'. The lower the ratio, the more rubber is in contact with the road. Although I don't have data, the rear tyre in Fig. 29 probably has a lower void ratio than the front.

11. NVH (NOISE, VIBRATION AND HARSHNESS)

If tyres and their dynamic behaviour are rather rubbery things to get hold of scientifically – with their literally and figuratively elastic properties. Noise, vibration and harshness are even more elusive. It is true that vibration can be measured exactly – so many cycles per sec (Hz) at such or such an amplitude. Sound can also be measured – so many decibels (dB) at this or that frequency (Hz). If the sound contains so many mixed frequencies that it approaches so-called 'white noise', the individual components can be separated (filtered) and measured. Trouble starts when we get to so-called 'harshness'. It is also a mixture of vibrations and sounds – but it is a subjective assessment of the 'ride' of a vehicle. This is how psychologically comfortable the vehicle feels when running. There again, sound only becomes noise in the ears of the listener. (Some reckon, for instance that the "*potato ... potato*" sound of a certain V-twin is heavenly. Others find the sound of a two-stroke hitting its rev-limiter both physically and psychologically painful.) The original aims of Thomson and Dunlop were to increase the comfort of vehicles – improve the ride – by reducing noise and vibration. After all, what gives a harsher ride than a horse buggy with iron-shod wheels? Clearly the developments of the 1890s were superior to what had gone before. However, times have changed, as have vehicle performances and driver/rider expectations. So, lack of noise, vibration and harshness of ride are still sought after qualities in tyres.

Treating the issue initially as a single topic, NVH, one point is clear. The subjective degree of acceptability depends on the frequency of NVH and its intensity. A noise or vibration of any frequency will be felt as unpleasant, even intolerable, when it is intense enough. Evidence suggests that lateral vibrations are less tolerable than vertical ones. Frequencies of 1-5 Hz (cycles/sec) affecting the main vehicle body – the sprung mass – are the ones characterised by the term 'ride'. They can have vertical (bounce), fore and aft (pitch) and roll (side to side components). These have the highest degree of comfort acceptability. When the sprung mass oscillates in the 5-25 Hz range, the term 'shake' is used. It is moderately acceptable. When the range for vibrations of the vehicle structure or its components reaches 25-100 Hz – which are both felt and heard – we have reached the subjective area of 'harshness'. The intensities at which this is subjectively acceptable are quite low. Frequencies higher than these are just called 'noise'.

Of course, noise and vibrations reach a rider from many sources such as the engine, the air intake, the exhaust, etc., as do those generated by the contact patch and tread impacting the road. These get transmitted through the m/c structure to the rider. That structure doesn't always absorb vibrations but may augment them through resonance. A fairing may at times act like a drum. Indeed, the tyre itself is a rubber-encased cavity and it can drum. Most riders find that the vibrations caused by a so-called arterial road – concrete laid in strips that are no longer quite plane – to be most irritating. Gravel aggregate surfaces can produce unpleasant fine vibrations. Sometimes it is not the noise from one's own vehicle that is a problem. The tyre noise when passing high-speed trucks on smooth asphalt can almost reach the pain threshold, even when wearing a helmet. Another unpleasant riding sensation is passing over cattle grids.[25]

The events at the contact patch have been described. The tyre rubber gets compressed into the patch, the side walls bulge out under the weight of the m/c. These effects then relax as the tyre emerges out of the patch. These compressions and expansions also create vibrations, dependent on the flexibility of the materials and construction. The nature of the tread pattern also causes noise and vibration as the various elements strike the road. Certainly an off-road tyre such as that in Fig. 26 would be problematic on a paved road surface.

'*Ride*' is very much affected by the wheel balance. Irregularities lead to pulsing, throbbing and sometimes unpredictable braking performance. These vibrations are symptoms of rhythmic stress on the tyre and so do nothing to enhance its life or performance. Wear is increased and so is rider fatigue. (Rare, but not unknown, is the misfortune to get a tyre that missed the production quality control checks. The tyre itself can be unevenly weighted, rather than the tyre on the wheel. This may be beyond the corrections possible with wheel balancing. This outside chance provides a reason for having the wheels dynamically balanced in a properly equipped workshop.)

More than any aspect of tyre performance, this question of 'ride' is subjective. Other aspects do have some objective criteria for judgement. A rider notices when a tyre wears out within 4000 km (2500 mi.). Also, one tends to notice when a rear tyre insists on trying to get ahead of the front. As Tom French implies, the ride of a m/c standing in the showroom is perfect – no noise, a distinct lack of vibration, infinite wear potential and no risk of sliding in the wet. It is only when it is taken out on the road that these factors come into play. Even then, the only direct experience of a tyre's contribution to NVH is the noise that reaches the rider through the helmet and above the engine, transmission, intake and exhaust noise. Everything else depends on the m/c itself – its frame and superstructure. These determine how the inevitable vibrations are carried up to the rider – either suppressing or augmenting them. This makes it almost impossible to compare the 'ride' provided by this or that tyre. In some cases it may be difficult even to compare the same tyre on the same model of m/c. If my front end is original but you have got 10 kg of lighting and disc-covering accessories on the unsprung weight of your front end, the ride provided by your tyre may differ from mine.

[25] This can be reminiscent of so-called 'washboard' surfaces in deserts. I have no experience on a m/c, but with a car on the Moroccan desert. The drive started off quite unpleasantly. It was excessively harsh – and as it got worse when accelerating up from, say, 30 kph to 60 kph (20-30 mph) I went slower and slower. Our local guide said, "Faster … faster!" Finally trusting him, I accelerated through that harsh phase and then indeed the 'ride' became quite pleasant – at 100-110 kph (60-70 mph)! At slow speed the tyres were not at fault but the suspension. It was transmitting the vibration induced in the tyres by the ribbed surface to the car. At the high speed the suspension 'seized up' because it did not have time to rebound. The car just skimmed over the washboard. One just had to avoid any rocks or potholes! By the way, riding over cattle grids at 110 kph (70 mph) is *not* recommended!

12. TYRE HEAT IN BIRTH, LIFE AND DEATH

Heat is critical for the birth of a tyre – and it can be responsible for its death. It also contributes to its life – and that of the rider. The birth starts with natural and/or synthetic rubbers. These are rather fluid – at best sticky goos. They go into a cocktail with many chemicals such as carbon black, antioxidants and accelerators. There are various recipes for various tyre specifications.[26] (To improve wear and grip properties, new developments also include silica.) This brew is warmed, pressurised and mixed in giant blending machines (so-called Banbury mixers) to give a gummy granulate. This is then rolled and pressed into non-sticky, soft slabs. These are further rolled to get the various basic sheets for building up the tyre – side walls, tread and other components. The ply materials – polyester, rayon, nylon or fine steel mesh, though usually polyester cords – are coated with another rubber compound. The steel beads are joined into a rubber ribbon and then looped to form the basic shape. The various layers are then laid around the form. The inner layer of tubeless tyres gets a coating impervious to air. Side walls and other carcass layers follow. The last layer added is the tread material. Before going into a metal mould to form the tread and to vulcanise the rubber of this so-called 'green' tyre (harden by forming chemical cross-links), it is coated with a lubricant to ease its release from the mould.[27] The mould subjects the green tyre to high pressure and temperature (150°-180°C) for 15-20 minutes. The composition of the layers, their number – and the hardening conditions – are determined by the particular tyre specification. So, only with heat is a modern tyre born.

Repeated examples of how heat is generated were given above. The most common way – because it is the way a tyre works and comes to life – is the tyre compressing and expanding through the contact patch. Depending on the *hysteresis* properties of the material, energy put into the compression is not given back fully on expansion, but retained as heat. Tolerance for this is part of the tyre performance – assuming that the tyre meets all the specifications for the m/c to which it is fitted, i.e. it is of the correct size, correct load index, the correct speed rating – and correct pressure.

Yet heat can be the death of a tyre – and the rider. Some dangers of over-heating a tyre were already mentioned. The worst consequence of excessive heat is to cause *reversion* of the vulcanisation process. The chemical reactions leading to a hardening of the rubber under heat and pressure are not irreversible. With enough heat the rubber can revert to its original semi-fluid state. This is disastrous. Not just on the surface but also within the interior, portions of the rubber take on the consistency of treacle. Layers can detach and be thrown off. (You may have seen strips of truck tyres at the side of the road.) A m/c rider may be lucky to survive such a catastrophe with his/her life.

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[26] R.W. Rivers (2001) gives a recipe for a common passenger car tyre from Goodyear. The finished tyre weighs 9.5 kg and starts off with 1.8 kg of 8 sorts of natural rubber, 2.7 kg of 5 different synthetic rubbers, 2.2 kg of 8 types of carbon black, 0.45 kg of fine steel cord for belts, 0.45 kg steel bead wire, 0.45 kg polyester and nylon cords and 1.3 kg of a mixture of 40 different chemicals, oils, waxes, pigments, etc.

[27] The rubber that vulcanises against the mould surface comes out as smooth as that polished mould metal. It also holds the lubricant. Before a new tyre can deliver its full grip potential it has to be 'run in' 150-250 km (100-150 miles) to scrub off this low friction film.

The consequences of fitting a tyre with a low load index are similar to those of under-inflation. Instead of too little air pressure to maintain the form of the tyre, the side wall construction is not strong enough to support the m/c weight. The sides bulge out more at the contact patch and, with the larger contact patch, more tread is compressed and expanded in and out of it. More squeezed and expanded rubber, more flexing out and in means more heat. More heat brings the tyre closer to self-destruction. Bad news!

The load-carrying capacity of any tyre is given in its full designation as the *Load Index*. A shortened version of the full range is given in Table 4. Of course, one could ask why manufacturers do not supply one tyre that supports all likely vehicle weights. Well, a tyre bearing a loaded Gold Wing has to be stronger, heavier and, perhaps, more expensive than a tyre for a 125 cc lightweight commuter m/c.

TABLE 4: TYRE LOAD INDEX (LI) CODES

LOAD INDEX	WEIGHT (kg)	**LOAD INDEX**	WEIGHT (kg)	**LOAD INDEX**	WEIGHT (kg)
28	100	**48**	180	**68**	315
30	106	**50**	190	**70**	335
32	112	**52**	200	**72**	355
34	118	**54**	212	**74**	375
36	125	**56**	224	**76**	400
38	132	**58**	236	**78**	425
40	140	**60**	250	**80**	450
42	150	**62**	265	**82**	475
44	160	**64**	280	**84**	500
46	170	**66**	300	**86**	530

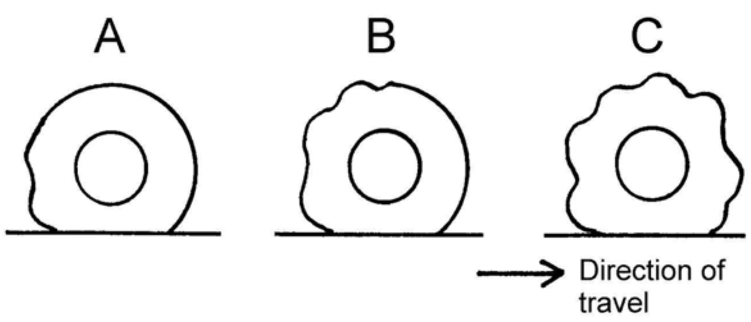
Related factors govern the *Speed Rating*. A tyre must be able to withstand the stresses produced at the maximum speeds of the m/c. These would be greater for a Fireblade than for a Super Cub. Again the construction is more complex, possibly using different materials. Speed ratings are also coded and included in the full tyre designation. Current codes are given in Table 5.

TABLE 5: SPEED RATING CODES FOR TYRES

CODE	MAXIMAL SPEED (kph/mph)	**CODE**	MAXIMAL SPEED (kph/mph)	**CODE**	MAXIMAL SPEED (kph/mph)
J	100/62	**Q**	160/100	**V**	240/150
K	110/68	**R**	170/106	**Z**	>240/>150
L	120/75	**S**	180/112	**W ***	270/168
M	130/81	**T**	190/118	**Y ***	300/186
N	140/87	**U**	200/124	* new, not yet fully standard indices	
P	150/93	**H**	210/130		

When a tyre is under-inflated, over-loaded or running beyond its design speed, there can be more happening than just the generation of excessive heat. The overheated tyre can vibrate itself to death. Figure 31 is meant to help with a greatly simplified description of this. To make the effects clearer they are greatly exaggerated. Picture A shows the relaxation of the tread and side walls as they emerge from the contact patch. Here the elastic spring properties of the rubber act, so that deformations only gradually die away. If the wheel turns quickly enough, as in B, one deformation has not died away before the next follows. Faster still, no part of the tyre has time to settle down. Not to be forgotten is the fact that the periphery of the tyre is subject to centrifugal force of its own. This exerts radial forces on the tread, tending to make the tyre bigger. These forces can start to resonate and lead to the formation of standing waves in the tyre – as does a rubber band when it is twanged rhythmically. This 'ripple' effect leads to rapid heat generation – and self-destruction of the tyre, usually through rubber reversion. Its occurrence is promoted by greater than normal deformations through the contact patch (under-inflation, over-loading) or with side walls too weak to support the speeds of rotation (speed rating too low).

FIGURE 31: SPEED DEFORMATIONS OF A TYRE



A final effect to be described occurs more commonly with aircraft tyres when landing but it can develop with road tyres. When a tyre is locked and skids or spins for long enough, extreme local levels of heat can be generated at the sliding wheel contact patch. (This can be worse if the surfaces are wet. Here, even internally, super-heated steam can form – because, as mentioned before, rubber compounds do absorb some water.) This heat can *very* rapidly lead to reversion of the rubber and its liquefaction. No, it is not often that a m/c lands at 200 kph or that it skids for a long time, but spinning a loaded tyre is like a prolonged skid. Tearing rubber generates enormous heat that can cause the tyre to destruct explosively – within seconds. A rolling tyre has some air-cooling. Vibrations or oscillations may be damped by the passage through the contact patch. The carcass is not exposed to excessive centrifugal force that can create standing wave ripples. Valentino Rossi's victory burnouts or 'doughnuts' are done with loadings of only about 140 kg and with very different tyres designed to operate at high temperatures. If a rider insists on impressing no one by doing a burnout, he should do it only when he plans to throw away the rear tyre before riding five metres on public roads.

Yet heat isn't bad in every aspect. The traction of rubber increases with temperature. However, only so much is acceptable – long before the rubber starts to fail in the ways described above. The fact that tyres get warm is built into their specification – those specifications of Load Index and Speed Rating are only relevant when the *cold* inflation pressure is used. When these are all met, in normal operating conditions the tyre temperature stabilises at about 80°-100°C. It then offers the best traction safely. This means that anything less offers less than optimal traction. Road riders do not normally do a warm-up lap before starting their ride, as do GP riders. Nor on public roads are they able to snake the m/c around to promote tyre warming. Therefore normal road riders have to be aware that their tyres do not provide optimal grip the moment they ride out on cool mornings. They should use a rough rule-of-thumb and not expect the best grip until 20 minutes or so into the ride.

13. GETTING TYRED – AND KEEPING IT THAT WAY

Because of the consequences of inattention to tyres, to speak of tyre maintenance is to speak of health and safety – of the rider. Some consequences resulting from the choice of or inattention to tyres – inattention to their health and safety – have been touched upon. We have seen many factors that could affect the life and function of m/c tyres – and the rider. There are further issues that do not need much discussion but will have to be mentioned. Therefore it is time to draw these factors together. However, before getting down to discussing what could harm a tyre, it is necessary to ensure that the right tyre is being used. That is in respect to size, load index and speed rating.

SIZE: It is difficult to believe but some riders do not know the correct size of tyre to use. It is the size recommended by the manufacturer! That information is given in the Owner Handbook – and if the handbook is not available, then any official workshop knows the size. Some countries define specifically the tyre and the manufacturer – this information is entered into the vehicle registration papers and may be checked any time. However, some countries only require the correct size. Yet others are indifferent.

This leads some riders to experiment with different sized tyres. Usually the choice is towards the widest rear tyre possible. There is an element of fashion in this – it being reckoned ultra-masculine to have a fat rear end. Usually these rear-end tuners claim that they are looking for more drive traction when, in fact, they have never slipped their rear wheel during acceleration. Others reckon that better acceleration will give them higher top speeds. As Kevin Cameron points out in his *Sportbike Performance Handbook* (1998), everything is a matter of swings and roundabouts – a gain here is a loss there. A wider tyre will cause power losses – and reduced top speeds in a straight line – due to increased rolling resistance. A wider tyre with a larger contact patch will provide more grip in a curve, but the m/c will be much slower turning into the curve and lifting out. It will be less 'flickable', more physical. A wider tyre is usually a heavier tyre, so increasing the unsprung mass. This could have noticeable, deleterious effects on the suspension. Then, there is the central reason for particular tyre sizes being recommended for a particular m/c. It is so that the tyres match the wheel rim size. Putting a wide tyre on a narrow rim cantilevers the side walls out at a greater angle. This makes them more susceptible to flex – and flex, as we have already seen many times, creates heat.

Cameron reckons that a wide tyre can be fitted only when the original rim is replaced to match the fat tyre. Easier said than done, because then there is the question of whether the swinging arm is wide enough for this, not to mention the need to relocate the brake calipers and the drive train. Nonetheless, assuming that this is all done, the potential problems do not end. It is possible that the swinging arm bearings do not have enough design tolerance to take up the additional stresses imposed by added traction. Also, the frame may be pushed beyond its limits and starts behaving like a demented ironing board when hit with a surge of torque in excess of design. In the light of this, Cameron suggests that one should:

> "either be happy with the tyres that are right for the bike, or trade up to a later model machine that already has the size tyres you want."

(I ask myself whether Kevin had his tongue in his cheek when he wrote this. Are there *really* riders whose choice of m/c is determined by the size of the rear tyre?)

Wider rear tyres can change performance in other ways. Take a m/c fitted with a Metzeler MBS 120/80 VB 16 – a recommended size with a rolling circumference of 1806 mm. This is switched to a MBS 150/80 VB 16, which should fit the rim but has a rolling circumference of 1951 mm. This difference in the distance traveled for each wheel revolution will increase the final drive gearing – on *all* gears – by a factor of 1:1.08. The wide tyre may have been fitted to provide traction for impressive getaways from traffic lights. However, the changed gearing may take a little shine off the gains.

It is rare that widths of front tyres are changed but it is interesting to examine one consequence, but that issue of gearing would come up here, too. Assume that a Metzeler M33 130/90-16 67H TL is the recommended front tyre, with its rolling circumference of 1933 mm. Thinking there might be profit with a low-profile tyre it is changed to a 130/70 VB 16 TL, with a rolling circumference of 1776 mm. For each wheel revolution, the distance traveled has dropped by a factor of 1.09. If the speedometer drive runs off the front wheel, because of that changed 'gearing', it will now read 9% too high. Of course if the change was made in the other direction – from a recommended /70 to a /90 tyre – it would read too low. A 9% excess speed could easily lead to a speeding ticket. So, unless the m/c has been suitably modified:

> **Tyre sizes should be according to the m/c manufacturer's recommendations.**

LOAD INDEX (LI): This was mentioned already and a table of codes given (Table 4). Assuming for a moment that it was possible to get a correctly sized tyre with a load rating twice that required by the m/c, it would be ill-advised to use it. Such a tyre is designed to function optimally when it is loaded within a particular range. A light-weight m/c would not get optimal performance from the tyre - mainly by failing to reach the optimal operating temperature. Such a tyre would probably be more expensive, so it would be a waste of money as well. Not just ill-advised but potentially dangerous would be fitting a tyre with a low LI. Tyres carrying weights above their construction limits overheat, give inferior handling and may provoke an accident. So:

> **Load Indices should be according to the m/c manufacturer's recommendations.**

SPEED RATING: Similar problems result if a m/c is ridden above its tyres' speed ratings. Overheating and self-destruction are real possibilities. Although tyre prices tend to be linked to tyre performance – higher performance costing more – the difference is marginal when compared to living or dying. Codes for these ratings were given in Table 5. Certainly there is no reason against choosing a tyre with a speed rating above that demanded by the m/c performance – except that it would be money down the drain. However:

> **Speed Ratings should be at least as high as those recommended by the m/c manufacturer.**

CONSTRUCTION: It was said that tyres have become an integral part of the vehicle design process. They are put on the drawing board at the same time as other items. This now goes as far as defining the type of tyre construction – cross-ply, radial – As well as dimensions. When a manufacturer of a modern m/c specifies the use of, say, radial tyres, radials and only radials are meant. The m/c has been designed to benefit from particular properties of radial tyres in respect to performance and handling. So:

> **The type of tyre construction should match that recommended by the m/c manufacturer – or, when different – should be legally permissible.**

TYRE DESIGNATIONS: Years ago, tyre designations used imperial units. However, although Napoleon started the spread of metric units, this process only went half way with tyre codes. There is a mixture of imperial and metric units! The magazine *Classic Motorcycle Mechanics* recently gave examples and explanations of these, as follows:

3.50-17 62P TT reinforced	3.50	the tyre width, in *inches*
	-	cross-ply construction
	17	rim diameter, in *inches*
	62	load index (here up to 265 kg)
	P	speed rating (here up to 150 kph/93 mph)
	TT	tube type (to be fitted with inner-tube)
	Reinforced (for the increased load capacity)	
150/70 B17 69H TL	150	tyre width, in *millimetres*
	/70	ratio of tyre height to width (70:100)
	B	bias belted construction
	17	rim diameter, in *inches*
	69	load index (here up to 325 kg)
	H	speed rating (here up to 210 kph/130 mph)
	TL	tubeless type (without inner-tube)
180/55 ZR 17 (73W) TL	180	tyre width, in *millimetres*
	/55	ratio of tyre height to width (55:100)
	ZR	radial construction
	17	rim diameter, in *inches*
	73	load index (here up to 365 kg)
	W	speed rating (here up to 270 kph/168 mph)
	TL	tubeless type (without inner-tube)

TABLE 6: TYRE DIMENSION EQUIVALENCIES

METRIC SCALE	IMPERIAL	U.S. ALPHA
80/90	**2.75**	
90/90	**3.00**	**MH 90**
100/90	**3.25, 3.60**	**MJ 90**
110/90	**3.50, 4.10**	**ML 90**
120/90	**4.00, 4.25, 4.60**	**MN 90/MP 90**
130/90	**4.50, 5.00, 5.10**	**MT 90**
140/90	**5.50**	**MU 90**

The old Imperial and/or US ‘alpha’ dimensions are no longer used but, with the help of a conversion table , such as Table 6), modern tyres can be found for older m/cs.

MIX 'N MATCH: Certain combinations of tyre constructions are, at best, ill advised, at worst, illegal. True, in the end the various constructions do the same thing – allow the vehicle to accelerate, brake and turn corners. However, they do this in different ways. These different behaviours at the front and rear can interact with the vehicle geometry to produce instability. The *Classic Motorcycle Mechanics* article listed some examples of legal and illegal combinations in the U.K., as in Table 7.

TABLE 7: SOME U.K. LEGAL(L) AND ILLEGAL (I) TYRE COMBINATIONS

TYRE TYPE	Cross ply (rear)	Bias belt (rear)	Radial (rear)
Cross ply (front)	L	-	L
Bias belt (front)	I	L	L
Radial (front)	I	I	L

'SHELF LIFE': It is not easy to get information about tyre ageing and the time for which they remain good. Some of the chemical processes going on during heat and pressure of production were mentioned earlier. None of these cease when the tyre is stored in a garage. They are at a greatly reduced rate, but continue they do. So anything that promotes chemical reactions is bad. Therefore tyres should be stored in a cool dark place – because light and warmth accelerate ageing processes. Tyres should be stored flat – so that they do not go 'out of round' – and not used as a shelf for, say, 10 sacks of cement. (Such use, as a shelf, would indeed shorten their shelf life!) Then atmospheric pollutants can attack tyres. Ozone is one hazard, but here it is not the ozone over the Antarctic but in the storage place. Tyres should not be stored near electric motors (compressors, air-conditioners, ventilators, Daddy's electric train set, the family deep-freeze, etc.) These spark. Electrical sparks produce ozone.

There is a tendency to think of rubber as rather resistant to aggressive chemicals in aggressive environments. After all 'rubber-like' seals are used in engines, bottles of acid, jars of pickled onions, etc. We forget that there are rubber and rubbers – and that the components and curing processes may differ widely. Therefore a good rule of thumb is to keep tyres away from any chemical – particularly organic solvents. These can attack the rubber, leach out some of the components, reverse the vulcanisation process and otherwise cause mayhem leading to a possible tyre failure on the road.[28] Any contamination should be cleaned off as soon as possible, using just soapy water.

Clean off all fuels, oils, solvents and chemicals immediately.

Even a correctly stored and protected tyre will age, and so lose important properties. Indeed, the U.S. Department of Transport (DoT) requires the date (week/year) of

[28] Kenneth Obenski (Motorcycle Accident Reconstruction and Litigation, 2nd edition. 1133 pp., Tucson (AZ), Lawyers & Judges Publishing Co., 1997) analyzed an accident that had no obvious cause. A rider and passenger went down on an urban curve, apparently riding at only about 30 mph. Detailed analysis of the rear tyre showed that it had been compromised chemically by oils on the left side. Inspection of the m/c revealed a defective engine seal on the left side, so that small amounts of transmission oil were being carried by the belt drive to the side of the tyre – seemingly for some time. Laboratory tests coated a new tyre with this oil. After just one day the oil was wiped off and the coefficient of friction measured. It had fallen by 10%. By the second day of exposure it had fallen by 30%! This was clear evidence that oil on the tyre was *not* the primary cause of the accident, as one might have imagined. The properties of the tyre rubber itself had been reduced by prolonged exposure to and penetration of oil.

manufacture to be imprinted on the tyre side wall. That is all very well, if it weren't for the fact that there is no public or readily available guidance on what use this date should be. When asking around about this I did hear that manufacturers would not bind themselves to a shelf life or a "Best Before" date because, they claim, they have no control of the storage conditions. That seems odd in that most other perishable goods – even those with extremely long lives – have such dates even though the manufacturer have no control over how, say, table salt, yoghurts, sausages or radio batteries, are stored. Recently though, Avon Tyres (UK) provided the CBX Riders Club (UK) with some info which I could back up with the kind help of Metzeler Tyres in Germany. So:

> **Unused tyres should not be fitted when they are 6 or more years old. Tyres already fitted should be replaced when they are 10 or more years old.**

IN USE CARE: So, the correct – in respect to construction-type, size, load index, speed rating and age – new tyres are fitted to the rims. How should they be cared for? Well, the first job includes caring for oneself. The wheels should be correctly balanced. (For today's high-performance machines, this should be done with the electronic equipment of a professional workshop.) If not, vibrations affecting the 'ride' and feel of the m/c can compromise grip, give uncertain handling, cause rider-fatigue and accelerate tyre and wheel-bearing wear. (If unusual vibration suddenly develops, one of the first things to check is whether the wheel-balancing weights are still in place.) So:

> **Wheels should always be correctly balanced.**

The next job is to give them a good scrubbing – with a road! It was mentioned that in the final moulding process the 'green' tyre is covered with a lubricant to facilitate its release from the mould. That and the initially very smooth tyre surface do not have good friction properties. So:

> **New tyres should not be over-taxed until they have been 'scrubbed in' by at least 150-250 km (100-150 mi) of riding.**

Following that, many demands are virtually identical to those given for storage. When the m/c is garaged, sources of ozone should be avoided. It is not good to rest the wheels against the central heating. Foreign substances should be kept away and – if getting on a tyre – should be cleaned off as soon as possible.[29]

As to ride preparation, most riding experts say that tyres should be checked before *every* ride for damage and pressure. I find that difficult advice to follow. With the standards of roads now it is rare to pick up anything damaging. (During the last 20 years and more than ¼ million kilometres, I have experienced two punctures.) Then, apart from adjusting pressures for extra touring loads, it was uncommon to make adjustments during the riding season. (*My* tyre pressures stay remarkably constant.) If experts are taken literally, a daily check should be made, say, on Wednesday, Thursday and Friday when a rider goes out for a 80 km (50 mile) spin – three checks for a weekday mileage

[29] When a m/c is not used for 2 months or so (as during a winter lay-up), part of the laying-up procedure is to jack it up to relieve the weight on the tyres – to prevent the development of 'out-of-roundness'.

of 240 km/150 mi. What checks does a rider undertake on Saturday – when he does an 800 km/500 mi. tour? Just at the start? At every fuel stop? After every 80 km?[30]

The reliability and durability of today's tyres has changed riders' perception of risk. An additional contribution to this change is the fact that although punctures happen, tubeless and radial tyres rarely deflate instantaneously. Of course we don't check our tyres regularly enough – and that is a mistake. A grave mistake, though, would be not to check pressures before riding differently to habit. This could be undertaking long-distance, high-speed highway riding or riding with heavy loads. Nonetheless:

> **The most important tool in a m/c is a reliable tyre-pressure gauge. Using it regularly is the most important maintenance activity.**

Making this mistake leads us to commit The Cardinal Sin. That Sin which could really get you to Hell – quite literally – is to ride with under-inflated tyres. Therefore:

> **NEVER (N-E-V-E-R) ride a motorcycle with under-inflated tyres.**

A moment earlier I confessed to the difficulty of following expert advice in checking tyres before every day's ride – short or long. So, it is up to every rider to decide what schedule of checks will ensure that he/she never rides on under-inflated tyres. Nonetheless, it seems that the minimally necessary 'maintenance step' is for a rider at least to walk around the m/c before starting each ride – paying particular attention to the tyres. He/she should get used to the feel/sound of a tap on them with a knuckle (as he/she should for the spokes of a traditional wheel). Although trivial compared to the use of a good pressure gauge, such habits are better than nothing. After all, a minor oil leak such as that described in the footnote above – a minor leak that could have major consequences – might be detected early.

WEAR: There comes a time when a tyre check tells the rider that the tyres are worn out and should be replaced. This is *not* when the carcass plies are visible through the tread. If the rider has any interest in his/her own life and limb, it is also not when the tread depth reaches the legal minimum (usually 1.6 mm). My rule of thumb is to replace them when the tread depth is down to 2 mm or as soon as they no longer 'feel' right – *whichever comes first*. (Recalling Chapter 10, Footnote 2 on p. 41, you will realise that I am a little more conservative than Bridgestone USA suggest I have to be.)

One thing a rider should do is to 'listen' to his/her tyres. After all, we all listen to the sound of the engine – tuned to any off-key sounds. We listen for vibrations of the chassis and fittings. Some of these may be serious enough to affect our safety. However, as said at the beginning, the integrity of tyres affects our safety 100%, every metre that we ride. Caring for them well, a rider will 'know' when they are healthy or not. He/she will be able to pick up the first symptoms of sickness. Wear will be one of them. It is a message to respond to and put to rights, not to keep hearing on every ride.

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[30] Tyre manufacturers are not unanimous in their advice as riding experts. Continental Tyres advise European riders to check their tyres at every fuel stop. Bridgestone Tires suggests that US riders should do the check every month. For me, one is too often, the other too seldom. And you? The choice is yours!

Going for a last ride on worn tyres may indeed be The Last Ride. Do not take chances. Replace them.

One of our m/cs is that Honda GL1200 Gold Wing. It has done about 240'000 km (150'000 miles) and since the first replacement of the original tyres it has always run on Michelin Hi Tour tyres. So, it has experienced many replacements due to wear. This front tyre on the 1200 is unique to all of the tyres we know. It works fully to my satisfaction without a murmur – until it wears out. It doesn't whisper a wear message. It shouts it. Almost from one ride to the next, when tread depth is down to 2.1-2.2 mm, the front end starts feeling a little light and slightly uncertain. (This is striking because of the tyre's 'silence' up to this point.) I suppose that I would be able to get another 1600 km (1000 mile) of use before the tread depth even approached the legal minimum. Maybe I'm funny, but during a ride I want to concentrate on the ride, not on the uncertainty up front. Although for a car, the relationship between tread depth and braking distances shown in Fig. 26 tells me something about my possibilities of dealing with a m/c emergency stop. I don't need that risk. I renew the tyre.

Get used to 'listening' to the tyres. Carefully examine them the very moment they 'say' anything different.

I am aware of the economics involved in this. I prefer the economy of saving my health to those few pennies. Yet how many pennies are involved? I can give an example in U.K. terms. With my style of riding an average life of these front tyres is 18'000 km (12'000 mi). A mail-order price is about £84. That means an extra 1600 km (1000 mi) of use is worth £7. That would be my saving if I continued with these tyres for that distance. Yet getting those 18'000 km out of the tyre, with today's prices, already cost over £1000 in fuel, not to mention oil, servicing costs, road tax, insurance, etc. Does it make sense to take chances on a tyre failing just to save £7 – less than 0.5% of the costs? What odds do you accept to gain these pennies against lose your life?

The smallest cost for, but greatest contribution to safety of, every mile ridden is in the tyres. Do not misjudge the economics of good tyre care.

ON TOUR: The state of tyre wear should be closely examined before any long tour. If there is any chance of the tyres wearing out before the end, one should find out whether tyres can be easily obtained, replaced and afforded in the places to be toured. (It would be unfortunate to sit waiting five days for tyres to be delivered express to some Mongolian dealer who charges five times the home rate.) If availability could be restricted, it is worthwhile to replace the tyres before starting the tour. It may seem to be throwing away some mileage on the tyres, but the cost and trouble of replacing them in foreign parts may be greatly more than this 'loss'. So:

Before a long tour, check whether the tyres have enough wear in them to get home – in case availability is restricted on the way.

REPLACING TYRES: With the widespread use of alloy wheels and tubeless tyres, it is no longer an easy job to change tyres oneself. Any ham-fisted damage to a wheel could compromise the seal between rim and bead. Bearing in mind a common Swiss saying – *Trust is good. Control is better* – even when tyres are changed in an official workshop, apart from getting tyres of the right specification it must be ensured that all work is done correctly as well. Part of that specification will be the 'directionality' of the tyre.

If a tyre is designed to roll in one particular direction, it must be mounted that way, as indicated on the side wall.

If the tyres are tubed, then the inner tube must be replaced with the tyre. The old tube has been stretched and stressed moving under one particular cover. Under the new cover this will be different, and potential weak spots will develop. It is also proper to check that the protective tape over spoke nipples is in good order.

When replacing a tubed tyre, always renew the tube as well.

When a tubeless tyre is replaced, the valve should be renewed as well. It has been exposed continuously to high centrifugal forces that can cause it to age and fatigue. A tubeless tyre may have some resistance to instant deflation with a puncture, but failure of that valve will be catastrophic. So:

Always renew the valve when replacing a tyre.

Care also has to be taken when reassembling the valve. M/cs such as the Honda GL1500 and GL1800 come with angled valves. These ease air-line access to the otherwise difficult-to-reach tyre valves. Because of their asymmetry they are exposed to additional centrifugal forces. Therefore Honda fit them with a plastic support that slides over the valve and slots on to the wheel rim. Omission of this could lead to valve shearing and instantaneous air loss at speed.[31] So, whether a home mechanic or professional workshop renews a tyre/valve:

Always ensure that the valve assembly is correct.

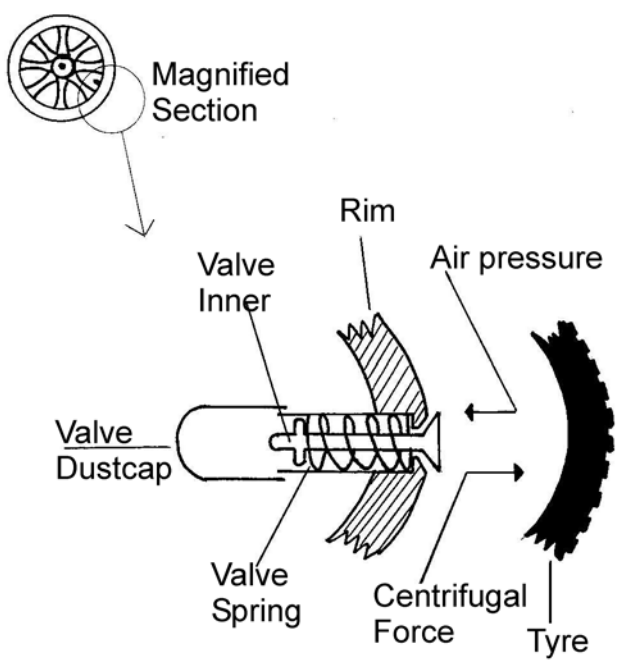
A mistake in the other direction – adding something to the valve assembly that should not be there – can also lead to valve failure. Such items are after-market angled adapters that also help make tyre inflation easier. The original valve assembly is *not* designed to carry these when the m/c is moving and it is foolish beyond measure to leave these in place when riding. Although they weigh only a little, those centrifugal forces acting on them are enormous. They can easily tear the valve away at high speed – again with *instant* deflation and disastrous consequences. This has happened to a rider of an early Gold Wing with Comstar wheels, 'straight' tyre valves and an after-market angle adapter left in place. Similar risks come from custom items. If fools will buy something, there will always be a supplier – of, for example, valve dust-caps in the form of dice, skulls, lights, etc. These have the same fatiguing effect on the rotating valve stem. So:

Never ride a m/c with a non-original tyre-valve air-line adapter still attached, nor with *relatively* heavy custom dust caps.

[31] A recent letter in the GWRRA magazine addresses this issue. (Because the published letter was unclear I contacted its Irish author – a policeman.) It concerned a second-hand GL1200 – and tyre valve failure and pressure loss at highway speed. The Irish rider and passenger suffered serious injury in the inevitable crash. The cause was that a previous owner had fitted a GL1500 angled valve to the 1200 – omitting that support bracket. The stressed valve stem finally split. The subsequent owner/victim did not know that this angled valve was non-standard or that it needed that bracket. Beware of back-yard mechanics!

When the valve is replaced, this should be one designed by the m/c tyre manufacturer. Based on an article in the German *MO* magazine in 1991, the reasons can be explained with the help of Figure 32. The valve principle is similar to that in an engine. The poppet is held in place by a tiny spring. On inflation, the incoming air pressure pushes the valve in against the spring, so that air can enter the tyre. Removing the air-line allows the spring to push the valve closed. The spring force and the tyre air pressure keep it closed. The latter is related to the area of the little valve-head and the tyre pressure – the dimensions of the valve.

FIGURE 32: SCHEMATIC REPRESENTATION OF A M/C TYRE VALVE



Now consider the m/c travelling at high speed. Centrifugal forces acting on the valve-inner tend to drive it into the tyre space. How much depends on the weight and size of these tiny parts. This is resisted by the spring. Resistance collapses if these forces exceed those produced by the spring (too weak) and the tyre pressure (too low). The valve will begin to leak and, as it leaks, the resistance from the tyre pressure lessens. More air escapes – and the process accelerates so quickly that it is almost instantaneous.

The magazine testers went down the High Street (well, *Die Hauptstrasse* in Germany) and bought five different automotive valve units, measured them and tested these on a sports bike. One spring force was only 25% of another. The lightest valve inner weighed less than 60% of the heaviest. In other words, there were tremendous variations in the valve specifications. A bike was run with correct (2.5 bar) and artificially low (1.5 bar) air pressures with dust-caps fitted. Only two valves withstood 150 mph without failing. One valve on an under-inflated tyre already failed at 105 mph. So, this lesson says:

When renewing tyre valves, do it with those supplied by the m/c tyre manufacturer.

The dust-cap was mentioned. It is not just a protection against dust entering the valve and dirtying the inner piston seal. A correct dust-cap is also the last defense against internal tyre valve failure. It will not protect against slow leakage but it prevents the *instantaneous* loss of air if the valve inner fails. So:

Always keep the standard tyre valve dust-cap properly in place.

Also mentioned earlier were the risks of over-heating the tyre. This could arise from running for a long time with low tyre pressures, allowing the wheel to spin excessively or, for the 'tuners', running the m/c on a dynometer. (The latter is particular damaging and should never be undertaken without replacing the tyres afterwards.) The problem is that damage may not be immediately apparent. It may have occurred internally.

If there is any suspicion that a tyre has over-heated, it should be replaced.

That point about a spinning rear tyre was mentioned earlier in connection with burn-outs. However, a rider does not have to do these to generate excess heat in the tyre. Riding on gravel or on a muddy rally site can cause wheel spin quite easily. However, prolonged wheel spin – and 'prolonged' means more than a few seconds, generates tremendous heat from the slippage. This may not end up with the tyre exploding, but the tyre may be seriously damaged internally and invisibly – leading to a later failure on the road. (I don't know about m/c tyres, but car tyres can explode if the wheels are locked up – and kept locked up – in a high speed skid.) So:

Do not allow the rear tyre to spin for more than a few moments.

It is now time to list the steps involved in repairing a damaged or punctured tyre oneself.

TYRE REPAIR STEP 1: **DON'T!**
TYRE REPAIR STEP 2: **REPEAT STEP 1!**

This advice refers to two aspects of tyre repair, the first being the tyre itself. A tyre that is damaged or punctured anywhere else but in the central area of the tread should not be repaired. The stresses on the side walls are just too great to risk anything but perfection there. Then, the damage seen from outside may in no way reflect the damage to inner surfaces. A nail can act like a 'dum-dum' bullet, causing a small entry hole but ripping a chasm on exit into the inner rim. That means that a damaged tyre must be removed for a complete inspection by someone who knows what they are doing, has the right equipment and knows what to look for.

By the way, another '*don't*' arises when a nail or the like is discovered in the tyre when you are away from home or a workshop. If the tyre is still holding air well, removal of the nail will certainly cause the air to escape. Ride slowly and carefully to the nearest repair shop.

Then there is the question of tyre removal and replacement. As noted above, most tyres today are tubeless, mounted on alloy wheels. Any clumsy use of a tyre lever can damage the inner rim and the tubeless bead will never seal and hold air again. The cost of having a professional workshop with suitable equipment do the work is a fraction of that for a wheel replacement. Then, sealing lubricants and rapid high pressure are required to get the bead to snap into place. It is not unknown for amateur tyre-changers to have a tyre explode and cause serious or fatal injuries. When the damage is modest a tubeless tyre can be repaired, but only on the advice of a professional. It is then done with a mushroom plug from the *inside* of the tyre.

It is possible for a home mechanic to repair or replace a punctured inner tube of a tubed tyre. Again, though, skill and knowledge are needed (like recognising the presence of a rim lock). Levering off the tyre may pinch the inner tube and damage it further beyond repair. Certainly the outer cover should be inspected. There may be more damage to that than to the inner tube. Levering the tyre back into place can also get the repaired tyre pinched and holed, putting the home mechanic back to square one.

> **If you lack professional skills and/or professional equipment, have tyres replaced and/or repaired by those that do have them.**

There are many products available for repairing punctures in tubeless tyres 'on the road'. They range from self-vulcanising plugs inserted from the outside to fluids that are squirted into the valve. These get extruded through the puncture and harden. Riding extra-cautiously, they must be viewed *only* as emergency 'get-you-home', 'get-you-to-the-workshop' measures. In *no* way should these be considered long-term repairs. Be thankful if they work and do rescue you from a difficult situation – and show your thanks by getting the damaged tyre repaired professionally or replaced at the *first* opportunity. (Professionals remove the tyre and, if it is reparable, do it from the inside.) Yes, there are stories of such amateur repairs surviving 10'000 km at an average of 150 kph. However, the angels can only look out for so many fools at a time.

> **Emergency kits for temporary tyre repairs are just that – for short-term use in an emergency. Damaged tyres should be professionally repaired or replaced as soon as possible.**

The legal situation in respect to running on repaired tyres is unclear in most countries. In the U.K., for instance, the 'Construction & Use Regulations' of 1986 require tyres to be maintained in a serviceable condition, correctly inflated, with sufficient tread depth and free from cuts, splits and other structural damage. There is, though, no mention of puncture repairs. However, the British Standards Institute has issued a standard to cover repairs. It is not a legal requirement but, as Dunlop advises, may be used by an insurance company as a test of 'prudence' and 'reasonableness' when assessing the cause of (and responsibility for) an accident. British Standard BS AU159/f states that the limits for puncture repairs are:

> For tyres with speed ratings up to "J", (up to 100 kph/62 mph) – 2 repairs up to 6 mm diameter *after repair preparation*; repairs must not overlap.
>
> For ratings above "J" and up to "V" (100-240 kph/62-150 mph) – 1 repair up to 6 mm diameter *after repair preparation*.
>
> Ratings above "V", including "W" and "Z" (above 240 kph/150 mph) – no repairs allowed.

In practice this means that scooter tyres and most cross-ply tyres *could be* repaired once, but high-performance sports tyres never. Anything outside these limits could result in an insurer refusing a claim associated with tyre-related accidents. On the other hand, it is all very well to speak of puncture hole diameters but the penetrating object may have damaged the cords. Structural and/or heat damage may have occurred before the vehicle was brought to a stop. No amateur can judge this, so inspection by a professional workshop is all the more important.

SHIMMY, WOBBLE 'N WEAVE: Instability of frames was not uncommon years ago when chassis design lagged behind developments in engine power. The power produced simply overwhelmed them – and they flexed under the stress. Now this is much rarer – even when riding way over the legal possibilities on public roads. Nonetheless, riders occasionally complain about wobble and weave. The first things to be checked are the steering head bearings and the rear swinging arm bearings. If these are not defective or worn, then suspicion should fall on to the tyres. Many riders have spent enormous time and money trying to solve a stability problem, only to find out that the cause lay in the rubber.

The terms 'shimmy' and 'wobble' get used interchangeably, though in the car world, wobble is an oscillation of one steerable wheel and shimmy the oscillation of both. Because a m/c has only one steerable wheel, perhaps shimmy is the term of choice – when all of the steered wheels oscillate. It is caused by the castor effect of the front wheel. As on the supermarket trolley a self-aligning force develops which jerks the wheel into line. However, the re-alignment doesn't stop when the wheel reaches the centre-line again. It jerks over to the other side and then back again – repeatedly. Once initiated it can build up into a veritable 'tank-slapper' as the handlebars swing from lock to lock – just before the rider crashes catastrophically. (It may be possible to accelerate through shimmy – but that is not solving the problem. Also, it may occur at an inconvenient time for accelerating.) It has a frequency of about 8-10 cycles/sec – similar to the wheel rotation frequency at 55-65 kph (35-40 mph), when shimmy usually occurs. (The frequency is relatively high because the trail distances causing the castor effect with the front wheel are short.)

If this appears on a m/c that was previously well behaved, the tyres are a prime suspect. Tyre pressures may be too high so that the tyre can't form its normal contact patch. They may just be worn, or have worn to a bad shape. They may be unbalanced. If the effect follows a change to a new tyre type, the tread contours or the particular tyre construction may not match the m/c. Perhaps there is now a mix of tyres that the m/c doesn't like. Whatever the cause, finding it must have highest priority – but fitting a steering damper is the treatment of symptoms, not a cure.

Weave is an oscillation of the rear end. At 2-3 cycles/sec is has a much lower frequency than shimmy. (The castor trail to the rear wheel is long.) On acceleration it only gets worse, to the point of disaster. Often it occurs on fast, drawn out curves – so-called 'sweepers'. If the tyres are indicted, then it is because of similar deficiencies that cause shimmy at the front end. Again, an immediate solution is mandatory.

If riding instability develops (shimmy, weave) the tyres must be investigated as a possible cause – as urgently as possible.

COMMONSENSE: This list of tyre-care tips is long. It could have been shorter by appealing to commonsense – on which it is based. Yet, many people seem unable to accept or understand that manufacturers of m/cs and tyres always have sensible reasons for the advice they give – not all concerned with profit. There are reasons for all dimensions of a tyre. There is a rhyme and reason for the tread – which is lost with wear. Specific air pressures have a purpose, as do valves, tiny dust-caps and so on. Some riders may think they know better than companies that have more than a century of tyre experience. Fine! Who am I to argue with these home-grown rocket scientists? However, other riders have more modesty, more commonsense. As with most things, it is commonsense that keeps a tyre in good trim. If a tyre is meant to be used so, and not 'ab-used' so, I am happy to allow commonsense to prevail. Nonetheless, my inherent curiosity obliged me to explore why use should be so, and why not abuse so. Now I know a little bit more – and that makes it easier to get a grip on my tyres.

AFTERWORD

In high mountains, there is small room for mistake.
Peter Matthieson, The Snow Leopard, 1978

I have tried to give the complicated reasons behind the very simple activity of caring for tyres. Initially I assumed that many riders would know some but not all of it. If we Europeans are similar to our U.S. counterparts, this assumption may be optimistic. As a basis for legislation on tyre markings the U.S. National Highway Traffic Safety Administration reported a study on the knowledge road users had about their tyres (Report 49 CFR Parts 567/571/574/575, 19.12.2001). Essentially the US lawmakers recognise the need of owners to choose and maintain tyres correctly but observed an indifference to this on the part of riders and drivers. One reason given was ignorance about where to find the necessary information. Earlier, with innocent abandon, I said that this information should be obtained from the Owner Handbook. I could have said from the information sticker on the vehicle.

In a filling-station survey, over 11'000 Americans were asked how they determine at what pressures to set their tyres. 24% said they let someone else do it. (!) 22% claimed they got the information from the tyre labelling. (The only problem with this is that labelling contains the *maximally* permissible inflation pressure but does not – and could not – contain all the possible individual vehicle- and current load-specific air pressures to use!) 11% said they judged the required pressure visually. (Huh!) Only 26 % used the Owner Handbook or vehicle labelling to ascertain the correct pressures.

How would Europeans fare in such a survey? If not already here, could such a situation arise? Have I been too optimistic in believing that riders want that information, know where to get it and, once it is in their hands and heads, use it conscientiously? Do they care enough about those few square centimetres of rubber that link their m/c to the road? Does it matter to them that these small patches are their link to Life or to Heaven or Hell? I dearly hope so – because the death of even one motorcyclist, an avoidable death at that, is just one too many.

In high mountains and on motorcycles, there is small room for mistake.
T.G. White, *Popular Philosophy for Motorcyclists*, yet to be written.

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