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The Expedition's West Tacoma fitted with 255/85 R16 BFG Mud Terrain (33.4 x 10.5")

Tire Selection for Expedition Travel: The impact of tire width on traction

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Position: A tall, narrow tire is a superior choice for all off-highway surface conditions with the exception of deep, soft sand or mud.

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Summary:

This is an empirical summary of my position. The supporting details of this argument are contained in the body of the document. The start of my study came as a result of asking the critical question. What is better for most trail surfaces; a wide or narrow tire?

This initially led me to research the physics of tire traction, which is mostly related to dynamic friction as the vehicles are not just parked on a surface trying to maintain a static state. There has been some research on the subject related to performance vehicles and race cars, operating on highly tactile surfaces, and running at high speeds (and subsequent heat generation), but there was no significant research done for off-highway vehicle operation. So I spent several months researching the subject, testing the logic and formulating a position. Why a position, and not a conclusion or "law" of tire performance? For me to proclaim a conclusion would require much greater testing volume, samples, variables etc., which time does not allow. So, the following is my position.

When driving off-highway, the performance of a vehicles tires is influenced by the elements of friction as related to the following items: Adhesion, momentary molecular bonding, deformation and mechanical keying (Haney, 2003). Where a race car operates on a highly tactile surface, which allows wide, even smooth tires to perform exceptionally (due to adhesion and bonding), an off-highway vehicle operates in the exact opposite environment, with minimally tactile surfaces. Rocks, dirt ledges, dusty boulders, highly irregular surfaces, sandy washes, etc. occupy the fourwheeler's environment. Surfaces that do not provide high adhesion rates or momentary bonding. However, these surfaces are highly irregular, which does provide the opportunity to take advantage of mechanical keying and deformation. These traction elements require high contact pressure, coupled with low air pressure to get the tire to flex with the terrain. A wide tire distributes the vehicles weight over too large of a surface, preventing deformation from occurring at the same rate as a narrow tire with the same pressure (force). A narrow tire will hold better than a wide one by keying to the surface aggregate due to the greater vertical force.

It is important for me to note that this document is NOT about reducing tire air pressure "airing down". Airing down provides its own performance benefits which are not covered in detail in this paper. For all examples assume that the wide and narrow tire are both at 15psi for the trail.

Abstract:

While the coefficient of friction (Ff = Cf x Fv) is linear and not affected by width (on a perfectly smooth surface, traction is consistent despite width), it is the variability of the road surface conditions off-highway that improves traction for a narrow tire. The greater the contact pressure, the greater of effectiveness of the friction elements of Deformation and Mechanical Keying. A narrow tire also presents less rotating resistance on a soft surface, like shallow mud, snow and sand. Additional performance is gained by the assumption that most vehicles can fit a taller tire if it is narrower, which provides greater axle clearance. Final arguments are made for the benefits related to reduced rotating mass and unsprung weight.

Assumptions:

The argument is further bolstered by the assumption that a taller tire can be fitted to the vehicle if it is narrower. For example, a Toyota Tacoma can fit a 33x10.5 with 2" of lift, but not a 33x12.5 with the same wheel off-set, suspension, etc. A taller tire allows the driver to air down further (maintaining sufficient ground clearance), increasing tire deformation on technical terrain and increased flotation on surfaces with low shear resistance (like sand).

The argument assumes that the surfaces encountered off-highway are not typically highly tactile, like concrete or asphalt, but are irregular, and loose, with poor surface condition (either dusty, muddy, wet, etc.)

This article is specific to heavy expedition vehicles with nominal lift and stock engines (as is desirable for extended travel reliability). The article is NOT about 1,500 lb. sand rails with high HP motors, or other competition platforms with one dimensional surface conditions.

Definitions:

Friction: (Mech.) The resistance which a body meets with from the surface on which it moves. It may be resistance to sliding motion, or to rolling motion. [1913 Webster]

Adhesion: Intermolecular forces that hold matter together, especially touching surfaces of neighboring media such as a liquid in contact with a solid.

Momentary Bonding: The brief molecular connection of two surface elements under heat, pressure or mixing.

Deformation: The change in geometric size, shape, form or position due to force.

Mechanical Keying: The interlocking of surfaces

Understanding Tire Placarding: As would be read on the sidewall of a tire

Reading a flotation tire: Example LT 31x10.5 R15 C

"LT"= Light Truck. Intended to be used on a heavier vehicle, with a higher GVWR than a typical passenger car.

"31"= The tire height, represented in inches.

"10.5"= The tire width at the section (widest point of the carcass), represented in inches.

"R15"= Indicates the tire is a radial and has a rim size of 15 inches.

"C"= The load rating of the tire. It can also be D, E, etc. The higher the letter, the greater the load carrying capacity.

Reading a metric tire: Example LT255/85 R16/D 119Q

“LT”= Light Truck Tire

“255”= The section width in millimeters

“85”= The aspect ratio. Expressed as a percentage of the section width (so 255*.85=216mm). The result is the height of the tires side wall. To determine the overall height of the tire, the following equation is used [(side wall height)*2+(rim height)=total tire height]. For the example tire the equation reads [(216*2)+406=838mm] Note: A 16” wheel is 406mm tall

“R”= Radial Construction

“16”= Rim diameter in inches

“D”= Load Range . Indicates ply rating (example tire is 8 ply), and load pressure, or the recommended tire pressure at maximum load (example tire is 65psi) Available Chart= http://www.tiresafety.com/size_class/size_nav4b.htm#plyrating

“119”= Load Index, which is the load carrying capacity of the tire (example tire is 2998 lbs.) A good load index chart is available here http://www.tiresafety.com/size_class/size_nav2.htm

“Q”= Speed Rating (example tire is 95mph). Available Chart= http://www.tiresafety.com/size_class/size_nav2a.htm

Understanding Off-highway Tire Performance:

Important note: For the sake of the following details, assume that the test vehicle is 5,000 lbs., and a narrow tire would be considered a 33x10.5 R15, and a wide tire would be considered a 33x12.5 R15, both run at 15psi for trail use.

The benefits of a narrow tire:

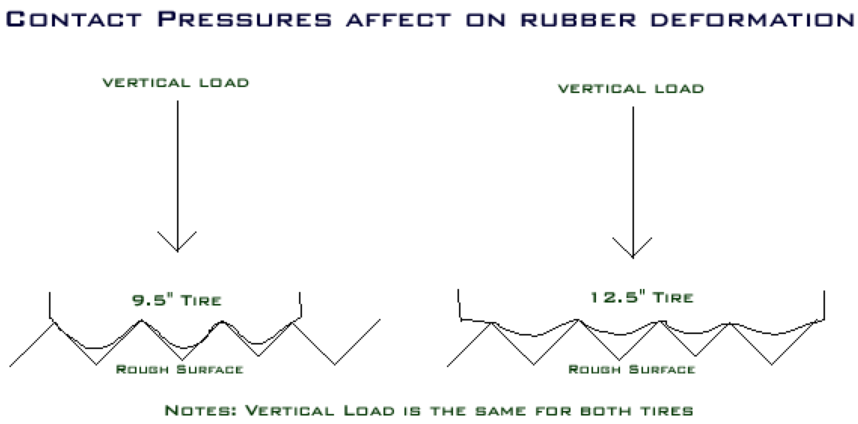
The Argument: A tall, narrow tire is a better choice for all off-highway surface conditions with the exception of soft sand, snow and soft mud that's depth exceeds 110% of the vehicles minimum ground clearance. Here is the explanation.

• **Contact Pressure:** Contact pressure is expressed as the vehicles curb weight distributed over the contact surface of four tires. The contract pressure is not equal to all four tire road surface contact points as the vehicles weight is not perfectly distributed. To ease the description, let's assume that the test vehicle weights 5,000 lbs and has a perfect weight distribution. Each of the vehicles four tires would be creating 1,250 lbs. of vertical pressure on the terrain. Let's assume for the sake of this example that the vehicles tires are 10” wide, where the load and tire pressure results in a total surface area of 30 sq. inches. The total pressure per square inch (without equating the secant) would equal 40 lbs.

Off-highway effects of contact pressure:

Deformation- On a smooth surface (like concrete), a tire gains most of its traction by adhesion. On an irregular surface like granite and boulders, a tires contact patch will deform as a result of vertical pressure. The wider the tire, the less the rubber will deform to the surface irregularity given the same vertical pressure. The greater the deformation, the greater the tires resistance to shearing forces (spinning). This is the strongest argument to using a narrower tire.

Real world example: When climbing a ledge with a jagged surface, the narrower tire will wrap the protrusions with more contact due to the increased deformation depth. The wider tire will rest on the surface of the protrusions and will have a greater chance of spinning (shearing).



Mechanical Keying: This is the second critical benefit of a narrower tire. As the vertical load increases, so does the compression and flexing of the tires tread and rubber to the surface protrusion. A narrower tire generates greater vertical load on the rubber and the tread, increasing tread compression in conformance to the surface irregularity. A wider tire in contact with more surface conforms less, and will shear sooner than a narrow tire.

Adhesion- On a flat surface, the adhesion rate of a narrow tire and wide tire are the same, as the wider tire makes more contact (friction area), but the narrow tire generates more pressure (vertical load force). On a highly irregular surface, the higher vertical load force of the narrow tire becomes an advantage, increasing molecular bonding between the tires rubber and trail surface. That bonding becomes so great that either the vehicle moves forward, the tire tears leaving rubber on the surface, or the trail surface breaks away.

Typical Questions:

What is the limit of a narrow tires effectiveness? Tire load capacity and rubber tearing. At some point the tire becomes so narrow and the contact pressure so high that the tires rubber molecular bonding cannot sustain the tearing load created by the bonding and mechanical keying to the surface. Remember, the width of a train rail cars wheel is only 4”, and they have incredible traction on a very smooth surface due to the intense vertical load force.

Why do race cars use wide tires? Lateral stability and cooling. Performance cars have wide tires for handling performance not acceleration. A wider tire exhibits less "roll-in" or deflection which affects tire camber and handling. Performance vehicles also drive at high speeds, which generate heat. A wider tire has a greater surface area to dissipate heat (generated from cornering and acceleration forces) at speed. Smooth performance tires rely on the highly tactile track surface with allows for exceptional adhesion.

• **Rolling Resistance:** A narrow tire presents less rolling resistance on improved surfaces, increasing fuel economy and performance.

• **Frontal Resistance:** This is another key benefit of using a narrow tire. When driving through mud, snow and sand a narrow tire presents less surface area to the medium. A narrow tire will cut easier through mud, snow and sand than a wide one (due to resistance). The best example of this is when turning in sand. When the front tires turn, they present a wider surface to the sand. You can feel speed reduce immediately when a turn is initiated because of the resistance.

• **Rotating Mass:** A narrower tire weighs less than a wider one of the same height. The difference in weight between a 33x10.5 and 33x12.5 is about 5 pounds, coupled with the narrower, lighter wheel, the affect on rotating mass is significant. A lighter tire and wheel is easier to accelerate and stop.

• **Size Fitment:** All things being equal, a narrower tire is almost always easier to fit with less fender trimming and total suspension lift that a wider tire of the same height. Wider tires affect turning circle, compression travel (which needs to be limited by lowering the bumpstops, etc.).

Practical Application: I find a good rule is to use as tall a tire as possible with the same section width as the widest tire available from the factory for that particular model. That way the tire will compress into the wheelwell designed for that width, without rubbing due to width. Example: I was able to fit my Tacoma with a 33.4”x10.5” tire with only a 1 ¾” lift. A 33x12.5” tire would require additional trimming, less wheel offset and lowered bumpstops.

• **Weight:** Without making this an article about suspension, one of the jobs of a properly engineered suspension is to control the cycling of unsprung weight, which is comprised of the axles (control arms, knuckles, etc. in an IFS), tires and wheels. The lighter those assembly's are, the easier it is for the suspension to control it, improving performance.

• **Airing Down:** This is another critical concept highlighting the advantage of a narrower tire.

As quoted from *Sahara Overland, a Route and Planning Guide* by Chris Scott (2004, ISBN: 1-873756-76-3):
"...Note that it's the diameter or height of the tyres that makes the difference in sand, and not, as many imagine the width... For the desert, you want tyres with a high aspect ratio of around 80 because this represents a taller sidewall so corresponds

to added ground clearance when firm, and a longer contact area when deflated"

Traction in soft surfaces: It is a common misconception that airing down a tire for off-road traction only makes the tire contact patch wider. That is not the case. In fact, only 20% of the increased contact comes from the width. 80% of the increased contact patch comes from the tread patch becoming longer. A tall, narrow tire allows for a very long contact patch when aired down. That, coupled with the minimal frontal resistance (area), negates much of the downside to narrow tires in flotation situations. The taller tire allows for a long contact patch and still maintains good ground clearance.

Traction on rocky trails: Another common misconception is that when airing down it is the increased amount of tire on the rock (more contact patch), that allows better traction. It is not the contact patch that creates better traction, but the tires ability to conform to the surface irregularities (deformation and mechanical keying). When an aired down tire comes in contact with a rock on the trail, the tires tread collapses under the vertical and horizontal forces, causing the tire to wrap the rock, as opposed to sitting on top of it. The wrapping effect provides greater shear resistance, and in turn better traction. (Technically: the shear load is distributed over multiple planes, not just a horizontal one).

Tire spring rate: One of the great benefits of airing down a tire is improved smoothness. Less pressure allows the carcass to flex. A taller tire has greater sidewall compression, and in turn a better ride. (expressed as compressive strength=N/mm). That is why your grandma's Cadillac had such tall tires…

Negative Effects: Nothing in the world is perfect, so there are some downsides to using a narrow tire…

Stability and high speed deflection- A narrower tire (and in turn a narrower overall vehicle track width) provides less stability on the road and on cambered trails. In addition, a taller, narrow tire's sidewalls deflect more under severe turning forces, causing the inside of the tires contact patch (midline to the vehicle) to lift (roll in) from the road, increase the chance of a high shear force skid, or loss of control.

Increased potential for trail damage- A tall narrow tire has greater contact pressure, so when crossing a sensitive area like a muddy track, the tire will want to dig down until traction is found as opposed to floating on top. Make sure to air down and apply light, smooth throttle to minimize trail damage, or just turn around and save the trail from any damage at all.

The Benefits of a Wide Tire:

The flotation tire provides three benefits. Greater high speed handling safety and improved lateral traction on constructed roads (concrete, asphalts, etc.), greater section width for support of the heavy vehicle on soft terrain, and appearance. The engineering concept behind the flotation tire can be found in its name. These tires were designed to provide flotation on loose surfaces like sand. Flotation only comes at the cost of contact pressure. Flotation is achieved by minimizing the surface pressure per square inch exhibited by the vehicle. These features are important for heavy, full size trucks and SUV's, but not most trail vehicles.

1. Improved handling: The wide tires on sports cars are not for traction under forward acceleration, they are for cornering grip (lateral). A wide, low profile performance tire provides the car with a wider track, and with minimal tire deflection. As a tire deflects under cornering loads, a portion of the inside (midline to the vehicle) tread is lifted off of the road surface, reducing grip due to the change in camber. In a flotation tire for a 4wd vehicle, the same applies. A wider tire (creating a wider track) improved cornering safety and grip. That is the reason most flotation sizes grow wider as they grow taller, to improve road handling and safety. It is important to remember that an improved road surface (like concrete) is highly tactile to the tires rubber, which is why a wide tire can performs well in forward acceleration on the road too (adhesion).
2. Greater Section width for flotation: A typical 33x12.5 all terrain tire will perform better on soft surfaces like deep mud, snow and sand than its metric equivalent (285/75 R16 or 33x11.2) as the weight of the vehicle is spread out over a larger surface area. The wider tread creates less stress to the surface tension of the strata of sand (as expressed in kN/m2) and the vehicle will not sink as easily. The smoother and wider a tire is, the better it will perform in sand, as the width creates flotation and the smoother tread displaces less sand under (horizontal) acceleration (shearing force). The same influences apply with snow and mud. If the snow and mud are deeper than 110% of the vehicles minimum ground clearance, than it is better to run a wide tire, aired down and have the vehicle “float” on the surface.
3. Appearance: Big flotation tires look great (in the mind of some). There are thousands of SUV's driving with wide, oversized tires as a fashion statement. For a vehicle relegated to pavement work and cruising, then the “balloon” tires are a good choice.

Negative Affects:

There are several negative affects to wide tires, many of which are the opposite of the narrow tires benefits. Wider tires weigh more, create more rolling resistance on the highway, are more difficult to accelerate and stop, etc.

Recommended Section Width: (Represented in typically available tire sizes)

This chart represents the recommended tire width, based on the vehicles weight (GVWR).

Vehicle GVWR	Mixed Terrain Typical	Soft Surfaces Typical
3,000-4,000	8.5-9.5" (215-245mm)	9.5-10.5" (245-265mm)
4,000-5,000	9.0-10.0 (225-255)	10.0-11.0 (255-285)
5,000-7,000	9.5-10.5 (235-265)	10.5-11.5 (265-295)
7,000-9,000	10.0-11.0 (225-285)	11.0-12.0 (285-305)
9,000-12,000	10.0-11.5 (255-295)	11.0-12.5 (285-315)
12,000-	10.5-12.5 (265-315)	12.5-14.0 (315-355)

Several Real World Examples: (just to show I am not the only one who believes in a narrow tire)

The Turtle Expedition who has literally traveled around the world used a 255/85 R16 (33.3 x 10) for many thousands of miles on their full size Ford. Land Rover uses narrow 7.0 R16 XCL tires in most of their Camel Trophy events. The Rain Forest Challenge and The Trophy challenge have all been won by the aggressive Simex Trekker tire (35x11.00). Tom Sheppard often uses the 7-7.5 R16 Michelin XZL and XCL for many of his expeditions. All very narrow tires in relationship to their height…

A Brief History of Tire Design and Engineering:

The History of Flotation Tires: Tires in the past were always tall and narrow. From the 4" wide solid train wheels to the earliest automobile, tires were always tall, and very narrow. It was not until the late 1970's that this trend began to shift, with the popularity of radial tires increasing, along with the size of American full-size trucks. These factors are what created a change from the older bias designs and sizes (Like 7.5 16, etc.). The trucks were bigger, heavier and traveled at faster road speeds, so the application of a wide tire became more appropriate.

Metric Tire History: Metric Tire engineering became standardized in 1964 with the inception of the European Tire and Rim Technical Organization (ETRTO). This consortium pursued design and fitment standards that optimized tire performance and safety in the European market. One of the first results was the creation of a standardized tire range and labeling method. The range first included the sizes of 235, 265, 285, etc. with aspect ratios of 75% of the tire width. The engineers determined that the ratio of 75% created the best compromise between handling safety on the road and low surface traction performance. As a result, metric tires for tight trucks are typically found in that aspect ratio (example= 265/75 R16).

Other Factors to consider in tire selection:

• Durometer, Viscoelasticity (Hysteresis)- I am going to touch on this lightly in this article, but a softer durometer rubber compound will have a much higher adhesion and deformation rate than a hard tire. There are several tires available with softer compounds, like the BF Goodrich Moab edition and the Goodyear MT/R. An easy test of the viscoelasticity of tire rubber is to press your thumbnail into the tread. The longer it takes to recover, the softer the durometer and higher the hysteresis. However, the softer tire will also wear out much faster.

• Siping- Siping is a great way to improve a tires traction. Siping provides greater tread deformation to the road surface, which is why it is so effective on icy and wet roads. The more the tire can conform to that very slick surface the greater the traction.

• Tread Design- On a high traction surface like dry concrete, a totally smooth tire has the greatest traction as the adhesion rate is highest between the two surfaces. On the trail however, surfaces are varied, including wet rocks, mud, dirt, etc. That is why off-road tires are so specialized and require a compromise of other capabilities. As a general rule, and aggressive all terrain tire with soft tread compound and siping will provide the best overall performance. A Goodyear MT/R or BF Goodrich MT with siping cut after purchase will also perform well in varied terrain.

Tread Design- Selecting the tread appropriate to the terrain you are driving.

Deserts: An all terrain tread without large shoulder block to displace sand under acceleration. Use a tall tire without heavy lugs and slightly wider than for hard surfaces (use a tire in the 75% aspect ratio range). Avoid rims taller than 16" as it is necessary to have sufficient section height to allow for a long contact patch (for flotation) when aired down. (recommended tires: BF Goodrich (BFG) All Terrain KO, Yokohama Geolander A/T+II's)

Mountains: The mountains will present the most rugged terrain, requiring the greatest clearance, traction and damage resistance. Choose a tall, narrow tire (in the 80% aspect ratio range). One that is a load rating or more above you GVWR requirement to ensure a sufficiently strong sidewall. Rocks, loose climbs and ledges are present on many mountain tracks. Use either an aggressive all terrain or a mud terrain tire in these conditions, and favor brands with stronger sidewalls. (Recommended Tires: BFG Mud Terrain and all terrain, Goodyear MTR).

Jungles: Jungle tracks require a tall, narrow, and aggressive tire. Large voids between tread blocks allow the tire to clear mud from the tire and maintain traction. The large voids also provide lateral control to help limit sliding and oversteer. Use the tallest tire possible (without excessive suspension lift), to allow axle clearance in deep ruts. (Recommended tires: BFG Mud Terrain KM, Interco Super Swamper Radial, Simex Jungle Trekker)

Section Width- A narrow tire will provide superior performance to a wide one. Wide tires are not appropriate for use on an expedition vehicle, unless they are crossing the Gobi. Contact pressure and its affect on adhesion, deformation and mechanical keying are the critical components of traction on rugged terrain.

Section Height- As a general rule, expedition vehicle tires do not need to be very tall, unless the vehicles break over, approach and departure angles require it. Typically a tire taller than 33-34" is not required. Do not select a tire that is so tall that it requires lowering the bump stops, or fitting the vehicle with a suspension lift of greater than 2-3 inches. Most well designed SUV's intended for extended, rugged terrain travel have sufficient clearance from the factory, or can be fitted with a minimal lift (1-2 inches). Of course, the larger the vehicle, the larger the tires that are mounted. Unimog's for example use nearly a 35" tire from the factory.

Resources:

Physical Chemistry of Surfaces. by Wiley. Adamson, A.W.

ERTO, *1998 Engineering Standards Manual* , *1998 Recommendations Guide*

Mechanics of Pneumatic Tires, U.S. Department of Transportation

The effect of inflation pressure on bias, bias-belted and radial tire performance (SAE) by B. L Collier

Racing & High Performance Tire: Using Tires to Tune for Grip and Balance
by Paul Haney

Questions / Comments?