HOW TIRES CHANGE A SUV'S PERFORMANCE IN FISHHOOK AND SINE-WITH-DWELL TESTING

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ABSTRACT

A 2004 Chevrolet Tahoe was tested with the Original Equipment Manufacturer's (OEM) base and optional recommended tires and wheels, and two sets of different sized aftermarket tires and wheels. One aftermarket tire and wheel set used a much larger and wider rim with a low profile tire that did not significantly change the vehicle's Static Stability Factor (SSF). The second aftermarket tire and wheel set used the larger optional OEM rim with a larger than recommended Light Truck (LT) designated tire that significantly lowered the vehicle's SSF. Tests were performed pursuant to the protocols described in the United States Department of Transportation (USDOT) National Highway Traffic Safety Administration (NHTSA) New Car Assessment Program's (NCAP) fishhook and sine-with-dwell maneuvers. Results demonstrated that changes in vehicle performance due to the use of aftermarket tires were dramatic. The lower profile tire and wheel combination produced vehicle tip-up in fishhook testing at 40 and 35 mph with and without ESC enabled respectively. The larger LT tire and wheel combination did not produce vehicle tip-up in fishhook testing with ESC enabled, but did at 45 mph with ESC disabled. Both base and optional OEM tires produced test results which fell in between the two aftermarket tires. The vehicle successfully completed the sine-with-dwell test maneuvers with ESC enabled and failed with ESC disabled when equipped with either the base or optional OEM tires.

INTRODUCTION

Vehicle manufactures provide information regarding the appropriate tires for their vehicles. Recommended tire and wheel sizes are printed on a placard which is affixed to the vehicle in an easily accessible area. Instructions in the Owner's manual typically state the recommended types and sizes of tires that are permissible or refer the operator to the vehicle's tire placard. A General Motors instruction found on the internet states, "GM Accessory wheel and tire systems are designed as a system and must be used as such. Approved tire and wheel system combinations can be found by clicking on a GM vehicle, brand, then model, which can be found on the GM Accessories Zone home page…GM strongly recommends that replacement tires be the same as the original equipment tires (GM, 2006)." Ford's 2000 Expedition Owners Guide states, "When replacing full size tires, never mix radial, bias-belted or bias-type tires. Use only the tire sizes that are listed on the Certification Label. Make sure that all tires are the same size, speed rating, and load-carrying capacity. Use only the tire combinations recommended on the label. (Ford, 2000)"

A tire manufacture described the appropriate tires for a vehicle as those that are recommended by its manufacturer, "To ensure the same performance characteristics intended by the vehicle manufacturer, replacement tires should be selected with the same size, load index, and speed symbol designation as shown on the vehicle tire placard and/or within the vehicle owner's manual." (Bridgestone/Firestone, 2006) Despite these types of instructions, the practice of installing tire types and sizes that do not meet the recommendations of the manufacturer was anticipated for a variety of reasons including customer requests and to meet vehicle modification requirements. Typical changes include "Plus" Sizing, Speed Rating changes, Passenger Tire vs. Light Truck Tire fitments, P-Metric vs. Euro-Metric, Standard Load (SL) vs. Extra-Load (XL), or combinations of the items above. Publications such as the "Tire Guide" published by Bennett Garfield provide Industry guidelines for some of these practices.

Daws described, "Plus" Sizing as, "the fitting of larger diameter rims and lower profile tires to vehicles (Daws, 2008)." Regarding "Plus" Sizing the Bridgestone/Firestone Replacement Tire Selection Manual instructs, among several points, that:

> "In some cases, a vehicle manufacturer may specifically advise against the application of replacement tires that are not the original size or type. Always refer to and follow these recommendations." And, "The overall diameter of replacement tires should be within vehicle manufacturer tolerances. If tolerances are not provided, use a guideline of +/-3% from the overall tire diameter of the tire specified on the vehicle tire placard." (Bridgestone/Firestone, 2006)

The fitting of tires and wheels different in size from that specified by a vehicle's manufacturer continues to be a significant commercial force in the tire marketplace. In 2008, according to Daws, "The fastest-growing segment of the tire market today is what is called the 'tuner' market. Another rapidly growing segment is that of low profile tires for light trucks and sport utility vehicles. The market for aftermarket wheels, tires, and suspension components in 2001 represented over $6 billion in sales."

Some of the important issues that must be addressed when considering tires that are different than those recommended by a vehicle's manufacturer include load capacity, tire pressure, tire clearance, and vehicle static stability factor (SSF) changes. These items can be analyzed using simple calculations, static measurement, and data supplied by tire and wheel manufactures. Unfortunately, these simple metrics do not address many other potentially negative characteristics that can occur to a vehicle's handling performance due to tire changes. These include yaw stability, rollover stability, cornering, ride harshness, rim to ground contact potential, tire debead, hydroplaning resistance, speedometer calibration, brake pad and steering gear wear and active precrash safety systems like anti-lock brakes, electronic (roll) stability control, and traction control. The research reported on in this paper principally addresses stability issues.

METHOD

The test vehicle was a 2004 Chevrolet Tahoe with VIN 1GNEC13Z04R177864, September 2003 manufacture date and an odometer reading of 64,285 miles. The vehicle was equipped with a 5.3L V-8 engine, 4-speed automatic transmission, 2-wheel drive, and Stabilitrac. Photograph 1 is an overall view of the test vehicle. GM's Stabilitrac will be referred to as Electronic Stability Control (ESC) from here on out. The tires recommended on the vehicle door placard were P265/70R17 inflated to 32 psi at the front and rear. The tires were mounted to the recommended alloy OEM 17X7.5 rims with a 31 mm offset. Prior to preparing the vehicle for testing it was researched, inspected and measured by a certified body shop to ensure that it had no prior major collision damage or repair and that it was in compliance with OEM specifications.

Photograph 1. 2004 Chevrolet Tahoe with VIN 1GNEC13Z04R177864.

Tires and wheels used in testing included: (1) Firestone Destination LE P265/70R17 inflated to 32 psi at the front and rear. The tires were mounted to alloy OEM 17X7.5 rims with a 31 mm offset; (2) Firestone Wilderness LE P265/70R16 inflated to 35 psi at the front and rear. The tires were mounted to alloy OEM 16X7 rims with a 31 mm offset. (3) Buckshot Maxxis Mudder LT285/70R17 inflated to 40 psi at the front and rear. The tires were mounted to alloy OEM 17X7.5 rims with a 31 mm offset. (4) Toyo Proxes S/T P305/40R22 inflated to 40 psi at the front and rear. The tires were mounted to alloy 22X9.5 rims with an 18 mm offset. Photographs 2 through 5 show the different tires mounted to their respective rims and inflated to the listed pressures.

Photograph 2. From left to right: (3) Buckshot Maxxis Mudder LT285/70R17; (1) Firestone Destination LE P265/70R17; (2) Firestone Wilderness LE P265/70R16.

Photograph 3. From left to right: (3) Buckshot Maxxis Mudder LT285/70R17; (1) Firestone Destination LE P265/70R17; (2) Firestone Wilderness LE P265/70R16.

Photograph 4. From left to right: (4) Toyo Proxes S/T P305/40R22 and (2) Firestone Wilderness LE P265/70R16.

Photograph 5. From left to right: (4) Toyo Proxes S/T P305/40R22 and (2) Firestone Wilderness LE P265/70R16.

The base vehicle's curb plus driver plus instrumentation weight with the 17 inch OEM tires was 5,785 lbs (F/R: 2,940/2,845). This included the driver (175 lbs) and the instrumentation (77.5 lbs) placed on the right front seat. Fishhook tests were conducted at or near the NCAP specified loading. The vehicle was fitted with an AB Dynamics steer robot to provide the programmed steer input. Calibrated instruments measured speed; slip angle; yaw, roll and pitch rates; x, y and z accelerations; and wheel heights. Brake line pressure at each wheel and brake pedal application status were also monitored and recorded. Brake pedal application status was monitored through a switch at the brake pedal. Signals from all instruments, velocity sensors and vehicle circuits were recorded with an on board data acquisition system at 200 samples per second. Data from the onboard instrumentation were post processed with a 6Hz, 12-pole, phaseless digital Butterworth filter and zeroed.

Tire pressures were set cold prior to tire conditioning and testing. OEM tire pressures were set to 35 psi front and rear for the base tire and 32 psi front and rear for the optional tire as listed on the vehicle's tire placard. The aftermarket tire pressures were set to 40 psi front and rear as recommended by tire retailers. Tires were conditioned and changed using the protocol dictated by the NHTSA NCAP fishhook test procedure (NHTSA, 2003). Tire pressure was monitored but not changed to ensure that no pressure loss occurred from test to test.

A series of static measurements and quasi steady state tests were conducted. These include measurements to determine: tire rolling radius, roll stiffness, roll moment distribution, CG height, and Static Stability Factor (SSF) and tests to determine understeer gradient.

Two dynamic tests, NHTSA's NCAP fishook maneuver (NHTSA, 2003) and NHTSA's sine-with-dwell maneuver (NHTSA, 2006) were conducted on the two OEM tire configurations. Only maneuvers in the left/right sequence were completed. The AB Dynamics steering robot generated the steering inputs for each run, while the driver controlled the initial speed. Tests were conducted at 35 to 50 mph and throttle was dropped prior to steer initiation. ESC off condition was produced by turning off the stability control switch on the vehicle console. Non-actuation of the system was confirmed by observing the warning lamp in the instrument cluster, and by monitoring individual wheel brake line pressures.

All tests were conducted on flat and level asphalt roadway and parking lot surfaces at the Southwestern International Raceway near Tucson, Arizona. The test surface had a 0.9 or greater friction coefficient determined pursuant to the ASTM surface friction characterization protocol. A listing of all dynamic tests is provided in Table 1.

Table 1. List of dynamic tests.

Tire	ESC	Test
Firestone Wilderness LE P265/70R16	off	Left-Right Fishook
Firestone Wilderness LE P265/70R16	on	Left-Right Fishook
Toyo Proxes S/T P305/40R22	off	Left-Right Fishook
Toyo Proxes S/T P305/40R22	on	Left-Right Fishook
Firestone Wilderness LE P265/70R16	off	Left-Right Sine-with-dwell
Firestone Wilderness LE P265/70R16	on	Left-Right Sine-with-dwell
Buckshot Maxxis Mudder LT285/70R17	off	Left-Right Fishook
Buckshot Maxxis Mudder LT285/70R17	on	Left-Right Fishook
Firestone Destination LE P265/70R17	off	Left-Right Fishook
Firestone Destination LE P265/70R17	on	Left-Right Fishook
Firestone Destination LE P265/70R17	off	Left-Right Sine-with-dwell
Firestone Destination LE P265/70R17	on	Left-Right Sine-with-dwell

RESULTS

Results from all static measurements, specifications, calculations, quasi steady state and dynamic test results are listed in Table 2.

The test vehicle exhibited the lowest rollover resistance when equipped with the low profile P305/40R22 tires and wheels during fishhook testing. The tip-up speed was 40 and 35 mph with and without ESC enabled respectively. The test vehicle exhibited dangerous tip-up response at 45 mph with ESC disabled when equipped with the larger LT285/70R17 tires and wheels during fishhook testing; the vehicle did not tip-up with ESC enabled. The test vehicle equipped with the optional P265/70R17 OEM tires tipped-up in fishhook testing with and without ESC enabled at 45 and 40 mph respectively. The test vehicle tipped up at 40 mph without ESC when equipped with the base P265/70R16 OEM tires, but did not tip up with ESC

Table 2. List of measurements, specifications, calculations , and test results.

	Firestone Destination LE	Firestone Wilderness LE	Buckshot Maxxis Mudder	Toyo Proxes S/T
Tire size	P265/70R17	P265/70R16	LT285/70R17	P305/40R22
Rim	OEM alloy 17X7.5	OEM alloy 16X7.0	OEM alloy 17X7.5	alloy 22x9.5
Rim offset (mm)	31	31	31	18
Tested tire pressure (psi)	32	35	40	40
Tire Diameter (in)[(1)]/percent greater to 16 inch OEM (%)	31.7/4%	30.6/0%	33.0/8%	31.6/3%
Static loaded radius (in)	14.80	14.24	15.54	15.08
Actual speed at 70 mph indicated (mph)	68.7	n/a	71.3	n/a
SSF	1.10	1.12	1.07	1.10
Roll stiffness (lb-ft/rad x 1000)	102	102	106	109
Roll stiffness distribution, percent front	60%	60%	60%	61%
Steer Gradient (between 0.1g and 0.375g, deg/g)	3.9	3.0	4.0	3.7
Tip-up speed in fishhook without ESC (mph)	40	40[(2)]	45	35[(4)]
Tip-up speed in fishhook with ESC (mph)	45	no tip[(3)]	no tip	40[(5)]
Sine-with-dwell, steer scalar at spinout or pass, with/without ESC	3.5/pass	3.5/pass	n/a	n/a

[(1)] Tire diameter was manufacturer's specification.

[(2)] Vehicle had simultaneous two-inch two-wheel lift, but no tip up (no outrigger contact) at 35 mph.

[(3)] NHTSA reports no-tip in NCAP information for ESC equipped 2005 RWD Tahoe, implied max test speed was 50 mph with default and supplemental steer scalar.

[(4)] Lowest speed tested.

[(5)] Vehicle had simultaneous two-inch two-wheel lift, but no tip up (no outrigger contact) at 40 mph.

enabled during fishhook testing sponsored by NHTSA.

Only OEM tires were tested using the sine-with-dwell steer maneuver. The Tahoe failed to meet the test criterion at a steer scalar of 3.5 with the ESC disabled when equipped with either the base or optional OEM tires. The Tahoe passed all runs resulting in successful completion of the maneuver with ESC enabled when equipped with either the base or optional OEM tires.

DISCUSSION

Often pressure is felt to place after market tires which do not meet the manufacturer's recommendation on a vehicle because of a customer's desire to produce a particular look that a tire can provide. In the case of the two aftermarket tires that were tested during the research reported on in this paper, one tire, the Toyo Proxes, produces a sporty look, while the other tire, the Maxxis Buckshot Mudder, produces a rugged off-road look. In the competitive world of retail tire sales it is common to get these kinds of requests from consumers.

Baseline data found in common fitment guides does not typically report on the effects of rubber compound as it relates to the appropriateness of the tire for a particular application, yet the rubber compound can have a significant effect on a tire's friction capacity. The range of friction coefficients is quite extreme when comparing a high performance tire to a light truck tire. A tire's friction capacity can greatly influence a vehicle's roll stability.

A typical tire fitment guide will provide information on alternative "plus" size tires and wheels that can be substituted by the tire retailer with the expectation that they will "fit". This often results in substituting the manufacturer's recommended tire size with a lower aspect ratio tire mounted on a larger diameter rim. The responsiveness of a low profile tire (small aspect ratio) will be significantly different than that of the more traditionally sized tire commonly recommended by the vehicle manufacturer. The vehicle responsiveness can influence a vehicle's roll stability.

The results of this study demonstrate the significant changes in vehicle handling that can occur when tires that are substantially different in design than that recommended by the manufacturer are placed on a vehicle. The changes that occur are not always intuitively obvious. This was clearly demonstrated by the results from the fishhook tests.

A review of the static measurements, specifications, and calculations reported in Table 2 would likely lead to an initial assessment that the base OEM tire would be the least likely to produce vehicle tip-ups during the fishhook test and that the larger Buckshot Maxxis Mudder tire would be the most likely to produce vehicle tip-ups in fishhook tests. One might also believe that the Toyo Proxes tires would produce vehicle tip-ups at similar speeds to the optional OEM tires. The results of the dynamic testing clearly demonstrate the error of such assessment in fishhook testing. In fact, the Toyo Proxes tires produced a violent tip-up response at the lowest test speed prescribed in the NHTSA fishhook protocol (35 mph). In contrast, the Buckshot Maxxis Mudder tires produced dangerous fishhook tip-up response at the highest speed of all the tires tested on the Tahoe during fishhook testing without ESC. Both the base and optional OEM tires produced tip-up results by the Tahoe that fell in between the results produced by the two aftermarket tires.

These findings clearly show the need for tire retailers to go beyond the standard fitment guides when determining what tires are appropriate for a particular vehicle or application. This is particularly true for SUV's, trucks, and vans that have lower SSF's and are more prone to rollover compared to passenger cars. The risk of significant safety hazard occurs when an aftermarket tire which does not meet the vehicle manufacturer's recommended tire type and size is on a vehicle. Aftermarket tires in this category should not be placed on a vehicle unless there has been full scale dynamic testing that demonstrates that the tires do not adversely affect the vehicle's handling characteristics.

The quasi steady state handling test results showed that the different tires did not significantly change the basic understeer characteristics of the vehicle. A typical driver would not likely know that they had substantially affected their vehicle's roll propensity when operating their vehicle under normal everyday driving circumstances with the aftermarket tires that did not meet the manufacturer's recommendations.

The ESC demonstrated its effectiveness in maintaining yaw stability during sine-with dwell testing with both the base and optional OEM tires. The Tahoe failed the sine-with-dwell test series at a steer amplitude of 130.2° (3.5 scalar) with both OEM tire sizes when the ESC was disabled. The Tahoe successfully passed the sine with dwell test series with steer amplitudes as high as 270° with both OEM tire sizes when the ESC was enabled. The ESC gave the driver the opportunity to steer the Tahoe more than double the amplitude without producing a vehicle spinout response.

CONCLUSION

1. Information about "plus" size substitute tires found in common tire fitment guides is insufficient to determine the appropriateness of a given tire on a given vehicle. Just because a tire will "fit" on a vehicle does not mean that it will be safe.

2. Aftermarket tires that do not fall within the recommendations for tire type and size provided by the vehicle manufacturer should not be placed on a vehicle unless full scale vehicle handling tests or analysis have been completed.

3. Driving a vehicle under normal everyday driving circumstances is not sufficient to determine the effect that an aftermarket tire may have on roll propensity.

4. ESC greatly increases a driver's ability to place steer inputs to a vehicle without losing control, or causing an on-road untripped rollover, thus significantly reducing danger and providing a significant safety enhancement. Tires that do not meet the vehicle manufacturer's recommended size may affect the functionality of the ESC system.

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