

Technical Analysis of a Proposed Shock Absorber Design Standard

Donald F. Tandy and Scott Hanba
Tandy Engineering and Associates Inc.

Robert Pascarella
Ford Motor Company

ABSTRACT

One important part of the vehicle design process is suspension design and tuning. This is typically performed by design engineers, experienced expert evaluators, and assistance from vehicle dynamics engineers and their computer simulation tools. Automotive suspensions have two primary functions: passenger and cargo isolation and vehicle control. Suspension design, kinematics, compliance, and damping, play a key role in those primary functions and impact a vehicles ride, handling, steering, and braking dynamics. The development and tuning of a vehicle kinematics, compliance, and damping characteristic is done by expert evaluators who perform a variety of on road evaluations under different loading configurations and on a variety of road surfaces. This “tuning” is done with a focus on meeting certain target characteristics for ride, handling, and steering. One part of this process is the development and tuning of the damping characteristics of the shock absorbers. This process is quite involved as there are many variables to adjust and while some characteristic may be good for one type of road or circumstance they be less desirable on others. This leads to a process of evaluating and tuning over a number of surfaces and conditions to develop the proper package.

Recently, in a series of three American Society of Mechanical Engineers (ASME) papers published by employees of an Arkansas firm (Engineering Institute or EI), a new and supposedly “novel” approach to shock absorber damping tuning was presented [1, 2, 3]. The papers propose a simple procedure which supposedly provides an automotive engineer with a method by which rear suspension shock absorber damping could be easily selected to provide appropriate damping to the vehicle. The work is based on experiments where three large rubber blocks are glued to single tire so that when the vehicle is driven it forces the rear suspension to hop and tramp. Several maneuvers modeled after the test standard SAE J266, Steady-State Directional Control Characteristics for Passenger Cars and Light Trucks [4], are then run. An objective metric based the maximum difference in steering from the vehicles calculated Ackerman angle is proposed to gauge vehicle performance. The authors of those papers even went as far as to declare vehicles with a “maximum steering delta” in their proposed test that exceeds four degrees as unsafe and defective. Additionally a theoretical model that assigns a percent critical damping value to a given set of shock absorber damping values, estimated suspension inertia, stiffness, and geometry was used. The authors of that paper have stated that vehicles with less than twenty percent critical damping, using that model, are unsafe. The authors attempt to support this opinion by plotting the “maximum steering delta” versus the calculated percent of critical damping and claiming a linear relationship.

This paper performed an in depth study into this proposed shock absorber damping design standard and vehicle performance metric as well as an in depth study on the supporting tests and studies that were used to support the theory. Additional testing was conducted on several production vehicles to evaluate the proposed methodology and metric. The mainstream technical community has endorsed the proposition that any test adopted as a standard for vehicle performance must be: reliable, repeatable, objectively quantifiable, and possess criteria that reasonably relates to vehicle usage in the real world. This paper employs that approach in a technical analysis of the proposed damping metric as well as the protocols for the tests themselves.

CITATION: Tandy, D., Hanba, S., and Pascarella, R., "Technical Analysis of a Proposed Shock Absorber Design Standard," *SAE Int. J. Passeng. Cars - Mech. Syst.* 9(2):2016, doi:10.4271/2016-01-1543.

INTRODUCTION

In recent publications [1,2,3] a simple vehicle test procedure was proposed in which rear suspension shock absorber damping could be selected to provide appropriate damping to the vehicle. In the procedure one rear tire is replaced with a tire that has three vulcanized rubber blocks approximately 1 ¼ inches thick and 6 inches in length equidistant about the circumference of the tire (see Figure 1).



Figure 1. The three hump “lumpy” tire

Vehicle tests which were loosely modeled after the SAE J266 recommended practice were performed. The main test which was utilized was based on the Constant Radius Procedure where the vehicle was driven on a path of a circle of predetermined radius while increasing vehicle speed. Steering was to be adjusted to maintain the path. Circles of different radii (90, 125, and 160 feet) were utilized in that study. A conclusion of that study was a procedure and metric that could be used to specify damping characteristics for new vehicles and could also be used to evaluate whether current vehicles may be “unsafe” in the event of rough roads or a tire tread belt detachment. A previous study [5] has looked at the relationship between the fabricated “lumpy” tire and real world tire disablements and found that they are not related. A second study [6] has looked at whether running “lumpy” tires in a steady-state test is even appropriate and found that it is not. It is not the focus of this paper to readdress those issues but rather the evaluation of the proposed procedure and metric cited above.

The metric as proposed by EI Consultants the “maximum steering delta” which they defined as the difference between the maximum road wheel angle (the steering wheel angle in degrees divided by the overall steering ratio) and road wheel angle required to drive at a near zero speed around the circle, also known as the Ackerman angle.

Test methods involve two factors: (1) protocol and (2) acceptance criteria. Both must be studied when reviewing a test procedure for its use as a proper scientific evaluations. Test protocols are often scrutinized for their validity, applicability, and accuracy. It is very important that the scope of the test method be clearly defined, and any aspect included in the scope is shown to be accurate and

repeatable through validation. One consideration is a tests usefulness to predict end-use characteristics, performance, and its ability to discriminate. As with the test protocol or procedure, the acceptance criteria will dictate what might be “good” performance and what may not be desirable.

RESULTS REPORTED BY THE EI CONSULTANTS

When publishing the results of the new metric, the “maximum steering delta”, EI Consultants only utilized the test runs in which the “lumpy” tire was on the inside of the turn. The reason for that was never given or explained. But from the analysis runs with the “lumpy” tire on the inside rear location, a “maximum steering delta metric” was derived and was plotted versus a calculated percent critical damping which was the subject of another EI Paper [7] (It is important to note the this paper was reviewed in a separate SAE paper [6] and was found to have many theoretical as well as simple mathematical errors).

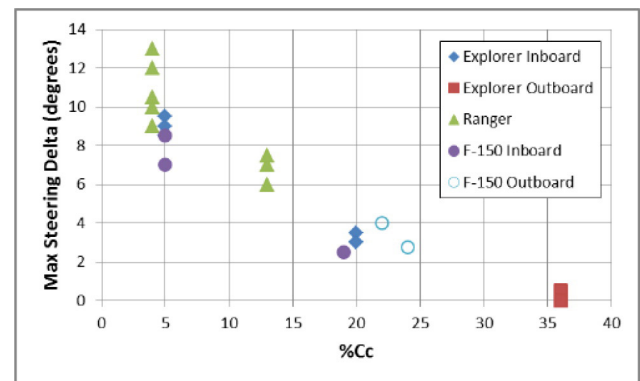


Figure 15. MAXIMUM STEERING DELTA VS. %Cc FOR 23 TESTS PRESENTED IN THIS PAPER

Figure 2. Result plot reported in [3] for the new metric on various production and modified vehicles

In [3] a plot was created to show the relationship between % critical damping and “maximum steering delta.” Based on the select vehicles and utilizing only the data from the runs with the “lumpy” tire on the inside rear tire it was stated that the relationship is essentially “linear.” This plot has been reproduced here in Figure 2.

Additionally, similar “lumpy” tire testing was conducted and presented in an earlier paper [1]. In that time frame, employed a smaller height “lumpy” tire and the EI consultants processed the data and would fit a line through the data as seen below. The criteria in that time frame was to subjectively fit a line through the data and generate an “understeer” value. In the run below that resulted and “oversteer” value of 18 degrees per g. This was then related to critical speed calculation of 21 miles per hour. This particular value was declared to show a vehicle defect (see Figure 3).

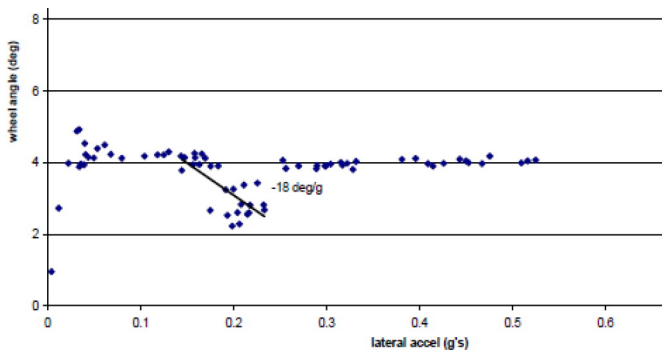


Figure 3. Result plot reported in [****] for a constant radius circle test run in the counterclockwise direction on a Ford Explorer

In the most recent EI Paper [3] this same test run and data is now used to calculate a “maximum steering delta metric” of approximately 2 degrees and is now considered acceptable. The total change in conclusions based on the same test and data was never explained.

EVALUATION OF THE EI NEW PROPOSED TEST METHOD

Utilizing the proposed three lump “lumpy” tire procedure, tests were run as part of this study on three vehicles; a 1998 Ford Explorer utility vehicle, a 2000 Toyota 4-Runner utility vehicle, and a 2005 Ford F-150 pickup truck (see Table 1). The vehicles were chosen as they all have solid axle rear suspensions and all have different shock geometry and damping values. In fact, two of them were tested in the ASME papers by the EI consultants. The data generated in these new tests was analyzed along with the rear shock absorber damping characteristics to compare vehicle performance and gauge the usefulness of the proposed procedure and metric.

Table 1. Vehicles tested as part of this study

	2005 Ford F150 Std Cab 4x4	1998 Ford Explorer 4-Door 4x4	2000 Toyota 4Runner SR5 4x4
			
Weight (lbs)	5198	4410	4042
Wheelbase (in)	126	112	106
Steering Ratio	19.0	18.4	20.9
	Calculated Ackerman Angle (deg)		
90 ft Radius	6.7	5.9	5.6
125 ft Radius	4.8	4.3	4.0
160 ft Radius	3.8	3.3	3.2

Three radii were utilized to test all three vehicles; 90, 125 and 160 foot, even though the J266 recommended practice [4] clearly recommends not running tests with circle radii below one hundred feet. Although each vehicle had a different specified tire size all three hump “lumpy” tires were made to same specification by the same supplier. As the size of humps clearly effect the vertical inputs into the suspension, the selection of the same 1 ¼ inch high lump as used by the EI consultants in their testing. The selection of the size of the

hump was never explained and appears to be arbitrary. However, in order to adequately evaluate the proposed methodology it was critical to utilize tires made to same specifications. Figure 4 shows the “lumpy” tire mounted to the right rear position on the Ford Explorer.

The test vehicles were driven on each of the three radii circle as stated above. The vehicle speed was slowly increasing while the test driver attempted to maintain course on the circle. The vehicle was instrumented to allow data acquisition of steering wheel angle, lateral acceleration, speed, and yaw rate. The data was sampled at a frequency of 100 Hertz. Runs were made with the 1 ¼ inch three hump “lumpy” tire on the inside of turn and on the outside of the turn.



Figure 4. Three hump “lumpy” tire on the right rear position of the Ford Explorer

As the vehicle speed is increased the “lumpy” tire causes vertical inputs to the vehicle which at some point resulted in forces that require steering changes to maintain the prescribed path. See Figure 5 which is an example of a road wheel angle versus speed chart for a 125 foot radius circle test on the Ford F-150.

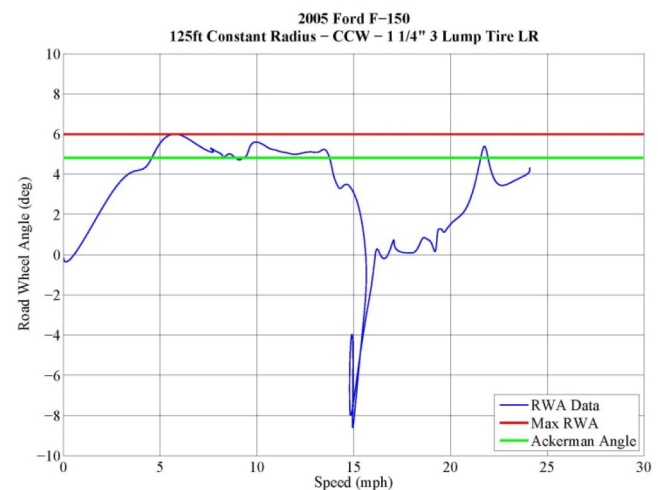


Figure 5. Example road wheel angle versus speed for the Ford F-150 on a 125 foot circle in the driving in the counter-clockwise direction

In the example data plot in Figure 5, the “maximum steering delta” would be approximately 13 degrees. In that paper this was only based upon tests in which the “lumpy” tire was on the inside of turn direction.

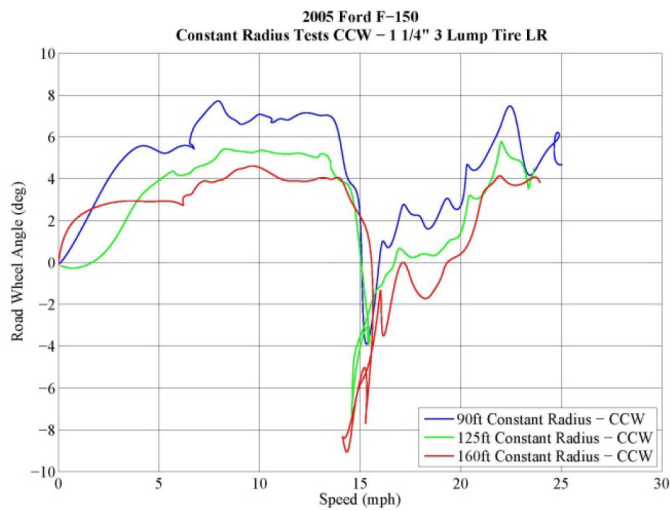


Figure 6. Example road wheel angle versus speed for the Ford F-150 on all three circles with the “lumpy” tire on the inside of the turn

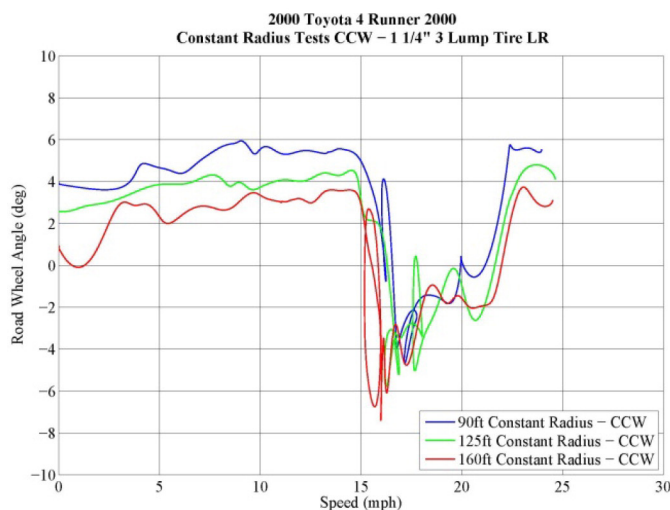


Figure 7. Road wheel angle versus speed for the Toyota 4Runner on all three circles with the “lumpy” tire on the inside of the turn

For the test runs in which the “lumpy” tire was on the inside of the turn, all three vehicles required a steering input towards the outside of the turn at a certain speed. See Figures 6, 7, and 8 which present the data for all three test vehicles with “lumpy” tire on the left rear and driven on circles of different radii in a counter clockwise direction. The data clearly shows that all three vehicles experienced a resonance of the rear suspension which required the driver to compensate by changing the steering angle. In fact, the steering corrections needed to maintain the path was towards the outside of the turn (i.e. counter steer) and in all three vehicles the magnitude of that counter steer resulted in the steering going past zero and into the other direction. This is irrespective of the location of the shock absorbers or their damping values. It is from analysis of plots such as these that EI

consultants had “measured” a “maximum steering delta” which is the maximum steering difference measured from the Ackerman angle for the given circle.

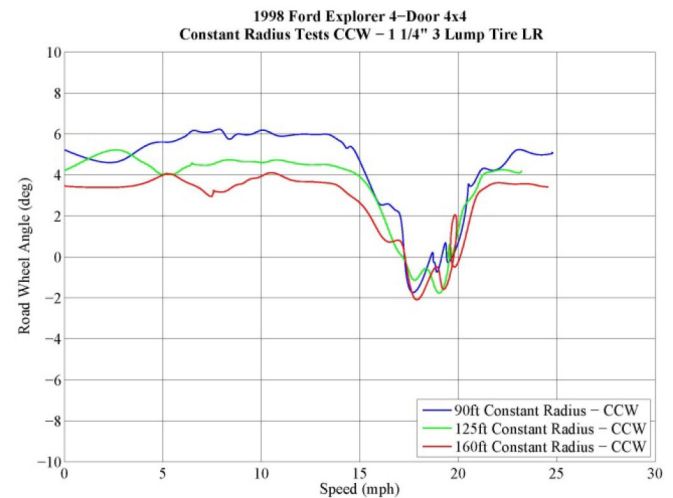


Figure 8. Road wheel angle versus speed for the Ford Explorer on all three circles with the “lumpy” tire on the inside of the turn

For the test runs in which the “lumpy” tire was placed on the outside rear tire location, all three vehicles required a steering corrections to maintain the path. But compared to the runs with the “lumpy” tire on the inside the results did not lead to a particular trend. See Figures 9, 10, and 11 for data plots of all three vehicles with the “lumpy” tire on the left rear and driven on circles of different radii in clockwise direction (i.e. “lumpy” tire on the outside of the turn). The change in road wheel angle found in Figures 6 through 8 are much less pronounced, especially on the Ford Explorer. If one intent of the “lumpy” tire is to simulate a tire tread belt separation then why do these vehicles appear to be “easier to control” according to the proposed metric with the “lumpy” tire on the outside of the turn? Scientific studies involving actual on track vehicle tests with separated rear tires have shown the opposite since the disabled tire has a reduced cornering capacity [8, 9, 10, 11, 12, 13].

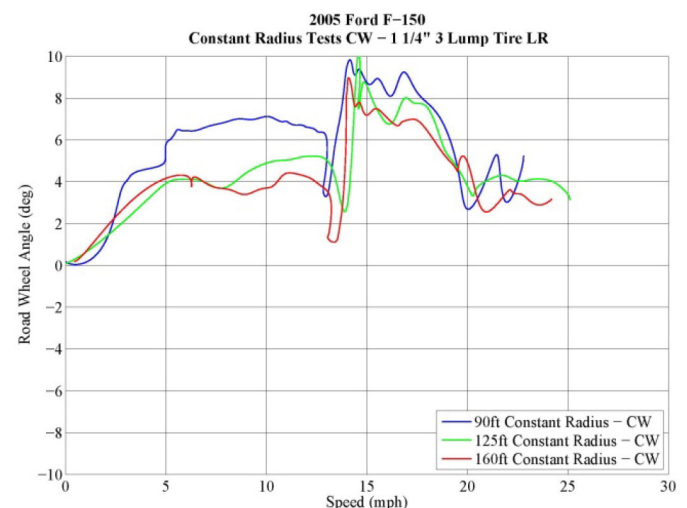


Figure 9. Road wheel angle versus speed for the Ford F-150 on all three circles with the “lumpy” tire on the outside of the turn