

Vehicle Coast Analysis: Typical SUV Characteristics

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ABSTRACT

Typical factors that contribute to the coast down characteristics of a vehicle include aerodynamic drag, gravitational forces due to slope, pumping losses within the engine, frictional losses throughout the powertrain, and tire rolling resistance. When summed together, these reactions yield predictable deceleration values that can be related to vehicle speeds. This paper focuses on vehicle decelerations while coasting with a typical medium-sized SUV.

Drag factors can be classified into two categories: (1) those that are caused by environmental factors (wind and slope) and (2) those that are caused by the vehicle (powertrain losses, rolling resistance, and drag into stationary air). The purpose of this paper is to provide data that will help engineers understand and model vehicle response after loss of engine power.

INTRODUCTION

“Coastdown testing has long been an effective means for determining vehicle resistive forces.” [1] The requirements for determining these deceleration values are testing, data analysis, and data correction for environmental variables. Few papers have been written regarding this topic. Indeed, this paper will provide a more detailed evaluation of coast down characteristics in regards to medium sized Sport Utility Vehicles. This more detailed evaluation will provide a better means of predicting deceleration values in a variety of situations that include stalling, loss of fuel pressure, and other non-catastrophic failures that would cause a loss of engine power.

It is important to understand that the final numbers presented may not be representative of significantly different vehicle types. The final results are best applied to medium sized Sport Utility Vehicles with possible

minor modification to the results to allow their application to smaller or larger SUVs. Significant variations in frontal area, vehicle weight, engine displacement, number of engine cylinders, and drivetrain may significantly vary decelerations from those presented in this paper. This paper will provide a good understanding of the reactions taking place during a coast down situation regarding coast down deceleration values relative to speed for medium sized Sport Utility Vehicles.

METHODOLOGY

TEST VEHICLE – The vehicle tested was a 2000 Jeep Grand Cherokee, which represents a mid-sized SUV. Mechanical specifications of the vehicle are given in Table 1.

Table 1: Test Vehicle Specifications

Vehicle Specifications	
Model Year	2000
Make	Jeep
Model	Grand Cherokee
Body Type	4 Door
Engine	4.7L V8
Driveline	Rear Wheel Drive
Brakes	Hydraulic
Fuel	Gasoline
Transmission	Automatic
Weight	1723.6 kg
Wheelbase	269.2 cm
Track	152.4 cm
Tire Dimensions	P245/70R16
Tire Pressures	227.5 kPa (cold)
Power Steering	Yes
Power Brakes	Yes
Air Conditioning	Yes



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NOTATION - The parameters presented in Table 2 are the necessary vehicle based values and symbols required for data correction and calculations.

Table 2: Variable Definition and Notation

Notation		
Title	Symbol	Definition
Wind Speed	V_W	Speed of the Wind (kph)
Wind Direction	θ_W	Direction of the Wind 22.5° CW Intervals (0°=North)
Vehicle Speed	V_V	Speed of the Vehicle (kph)
Vehicle Direction	θ_V	Direction of the Vehicle (NNW=328.7° SSE=148.7°)
Vehicle Frontal Area	A	Frontal Area of Vehicle (2.17 m ²)
Coefficient of Drag	C_D	Vehicle Coefficient of Drag (0.45)
Air Density	ρ	Density of Air (1.2 kg/m ³)
Vehicle Mass	m	Vehicle Mass (1723.6 kg)
Active Wind Angle	$\Delta\theta$	Angle Difference between Wind and Vehicle
Track Grade	θ	Track Grade (%)
Drag Velocity	V_D	Dynamic wind to vehicle velocity (kph)
Drag Force	F_D	Aerodynamic Drag Force imposed upon Vehicle (N)
Slope Drag Force	F_G	Slope Drag Force imposed upon Vehicle (N)
Drag Acceleration	A_D	Drag Acceleration imposed upon Vehicle (g)
Grade Acceleration	A_G	Grade Acceleration imposed upon Vehicle (g)
Real Acceleration	A_R	Acceleration measured during testing (g)
Corrected Acceleration	A_C	Acceleration corrected for grade and drag (g)

THE TRACK – By using a precision GPS system (OXTS RT3002) to map the track with a 200 Hz sample rate, it was determined that the slope of the timed mile portion of the Skid Pad at the Transportation Research Center in East Liberty, OH was consistently 0.5%, increasing in altitude in the Northbound direction. The altitude and position of the SUV was measured by the GPS system. By taking the derivative of altitude with respect to distance traveled, the slope could be calculated. The calculated 0.5% grade was consistent with the value reported by the Transportation Research Center. This slope was also consistent with allowable values presented by other research [1]. Figure 1 shows a slope profile of the entire Skid Pad at the Transportation Research Center. Noted are the boundaries for the

timed mile portion, which was determined to have a reasonably constant slope.

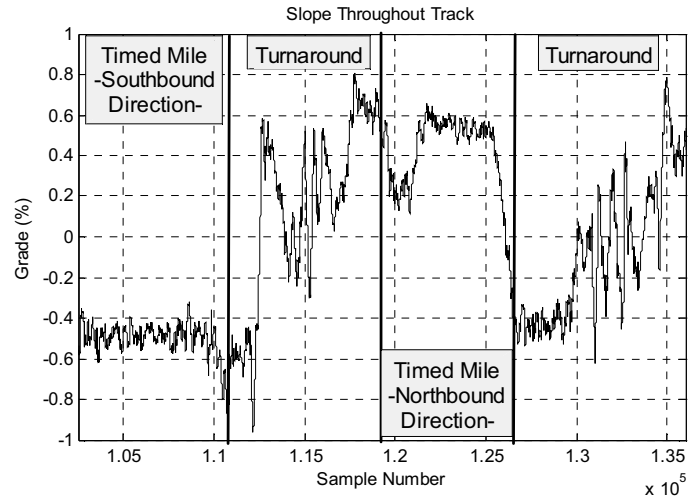


Figure 1: Measured Slope Throughout Skid Pad at TRC

All weather data was obtained by the Transportation Research Center as it is logged in 10 minute intervals. These temperature, wind speed, and wind direction data points provided the capability to estimate wind drag forces on the SUV. On the day of the test there was no rain and the temperature ranged from 23.2°C to 27.2°C. As the temperature change was not significant to affect results, the only weather variables needed for the analysis were wind speed and direction. Table 8 in the Appendix provides a summary of the weather data along with other pertinent information, including the test number.

PROCEDURE – Since the goal of this analysis was to determine the coast down performance of a medium sized Sport Utility Vehicle in many real world situations, testing was conducted with the transmission in neutral and in drive to provide an estimate of powertrain losses. Engine power was stopped by either turning the key to the off position or by pulling the fuse for the fuel injectors. It was important to perform the testing in both directions to provide a comparison of the effect of the grade and wind. Also, the testing was performed at many different coast-starting speeds.

An infrared optical sensor was used to measure crankshaft RPM and an optical “fifth wheel” was used to measure vehicle speed. Steering torque was obtained by using a secondary steering wheel with a strain gauge array designed for measuring steering torque. A photo of the instrumented steering wheel is shown in Figures 5 and 6, in the Appendix. A photo of the entire vehicle setup is shown in Figure 6 in the Appendix.

Using this setup, the testing procedure was performed in the following manner. The first part of the study was conducted by testing the coast down characteristics of the SUV by turning the key to the off position. Each test began with the driver accelerating to a desired initial

speed (15, 30, 45, or 60 mph – corresponding to 24.1, 48.3, 72.4, or 96.6 kph). When the vehicle reached the desired speed, the engine was turned off with the ignition switch. The Data Acquisition System was triggered and began to take data. The driver would either leave the SUV in drive or shift into neutral immediately after the engine was shut off. While coasting or driving, the driver provided varying random steering inputs to gauge maneuverability and to compare steering efforts with and without power steering. The steering inputs were typically within ± 120 degrees (left or right of center) and long enough in duration to either move significantly laterally in the initial test lane or to change lanes entirely. The last 10 tests (31-40) were run in the same manner; however, the fuel injector fuse was pulled instead of turning the SUV off via the ignition. The testing was also performed in such a manner that data was obtained going in both directions for each test condition. This allowed better comparison of the data with respect to a level plane with no wind. [1]

CALCULATIONS

UNCORRECTED ACCELERATION – Using the obtained vehicle velocity data, vehicle accelerations were calculated and corrected for slope and wind drag. Also, calculations were made to obtain stopping distances and drag factors from various initial speeds. The following calculation method will demonstrate how the data was modified to correct for wind and track grade variables.

Knowing the vehicle direction, wind direction, and wind speed, wind-related aerodynamic drag forces (attributed to ambient wind speed on top of vehicle speed) could be factored out of the raw deceleration values. Raw deceleration values were calculated using a numerical methods approach of Linear Least Square Regression. The Linear Least Square Regression method calculates two constants, which are used for slope and y-intercept values. The general equation is as follows.

$$y = a_1x + a_0 \quad (1)$$

The value of the constant a_1 is the slope, and therefore the acceleration of the velocity curve. The equation to derive a_1 is from Linear Least Square Regression Theory, and is given as follows:

$$a_1 = \frac{n \sum_{i=1}^n x_i y_i - \left(\sum_{i=1}^n x_i \right) \left(\sum_{i=1}^n y_i \right)}{n \sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2} \quad (2)$$

All x values corresponded to time while y values corresponded to velocity in the analysis [2].

The regression was performed so that accelerations could be calculated at the following speed intervals (in

kph): 0-16.1, 16.1-32.2, 32.2-48.3, 48.3-64.4, 64.4-80.5, 80.5-96.6, and 96.6-112.7, corresponding to 10 mph (16.09 kph) speed intervals. Two additional small intervals, before and after the torque converter decoupling speeds, were also analyzed (29.0-35.4 and 35.4-45.1 kph).

EXTERNAL VARIABLE CORRECTION – After the raw data acceleration values were calculated, they were corrected for external variables such as track slope and wind. Knowing the wind speed, wind direction, vehicle speed, and vehicle direction, one can calculate the acceleration/deceleration that wind imparts upon the vehicle. The following equations show how the acceleration/deceleration associated with wind was removed from the raw data acceleration. Refer to Table 1 for variable definitions and symbols.

Only the forces resulting from wind hitting the front or rear of the vehicle were considered and therefore, the active wind angle needed to be determined.

$$\Delta\theta = \theta_v - \theta_w \quad (3)$$

The wind drag velocity could then be determined.

$$V_D = V_w \cos(\Delta\theta) \quad (4)$$

Using the frontal area of the vehicle (determined using a photograph, known dimensions, and grid paper), air density, and aerodynamic drag coefficient [3], the drag force could be determined by the equation:

$$F_D = \frac{1}{2} \rho V_D^2 C_D A \quad (5)$$

Finally, knowing the mass of the vehicle, acceleration/deceleration due to the wind could be determined.

$$A_D \left(\frac{m}{s^2} \right) = \frac{F_D}{m} \quad (6)$$

$$A_D(g) = \frac{A_D \left(\frac{m}{s^2} \right)}{9.81} \quad (7)$$

Knowing the direction that the vehicle was traveling and the magnitude and direction of the slope of the track, slope acceleration/deceleration could be factored out of the raw data acceleration. The following equations show how slope acceleration/deceleration was removed. View Table 1 for variable definitions and symbols.

$$\tan(\theta) = \text{Grade} = \frac{\text{Rise}}{\text{Run}} \quad (8)$$

