

Development of a Roll Stability Control Model for a Tractor Trailer Vehicle

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ABSTRACT

Heavy trucks are involved in many accidents every year and Electronic Stability Control (ESC) is viewed as a means to help mitigate this problem. ESC systems are designed to reduce the incidence of single vehicle loss of control, which might lead to rollover or jackknife. As the working details and control strategies of commercially available ESC systems are proprietary, a generic model of an ESC system that mimics the basic logical functionality of commercial systems was developed. This paper deals with the study of the working of a commercial ESC system equipped on an actual tractor trailer vehicle.

The particular ESC system found on the test vehicle contained both roll stability control (RSC) and yaw stability control (YSC) features. This work focused on the development of a reliable RSC software model, and the integration of it into a full vehicle simulation (TruckSim) of a heavy truck.

INTRODUCTION

According to the Large Truck Crash Facts 2005 [1] released by the Federal Motor Carrier Safety Administration (FMCSA) in February 2007, there were 4932 large trucks involved in fatal crashes in the year 2005. Tractor-semitrailers were involved in 3077 (62.4%) of this total. 6x4 tractors constitute a major part of the air-braked vehicles being manufactured every year. All

manufacturers of 6x4 tractors sell ESC systems either as standard or optional equipment.

ESC, a generic term defined by SAE, may have only a Roll Stability Control (RSC) feature in it or may include a combination of Roll Stability Control and Yaw Stability Control (YSC) features. The RSC system senses the lateral acceleration and if it approaches critical values, then the RSC system applies braking on the wheels and reduces the lateral acceleration. The YSC system, in addition to lateral acceleration, also senses the yaw rate and steering wheel angle to determine the intended path. Based on the inputs it receives, the YSC system applies the brakes on individual wheels to prevent any excessive understeer or oversteer [2]. This paper deals with the research work done to develop an RSC system model to be used in conjunction with a vehicle dynamics model of a 6x4 tractor and trailer.

VEHICLE TESTING AND DATA ANALYSIS

VEHICLE INFORMATION

A tractor-semitrailer combination was used for this study. It had a Volvo tractor and a Fruehauf van trailer. The Volvo tractor had a factory-installed ESC system which had both RSC and YSC features. The trailer was retrofitted with a trailer-based Roll Stability Control (RSC) system from Meritor Wabco Vehicle Control Systems. The vehicle details are as follows:

Table 1: Vehicle Information

	Tractor: 2006 Volvo VNL64T630	Trailer: 2001 Fruehauf
Configuration	6 X 4	53 ft (16.15m) Dry Van
Wheelbase	211 in (5.36m)	464 in (11.8m)
ABS System	Bendix ABS 4S/4M	Meritor Wabco Trailer ABS 4s/4m
Brake Type	Meritor S-Cam—15X4 F 16.5x7 R	Meritor S-Cam—16.5X7
ESC	Bendix Electronic Stability Program (ESP)	Meritor Wabco Roll Stability Support

VEHICLE TESTING

The vehicle was tested on the Vehicle Dynamics Area of the Transportation Research Center Inc. in East Liberty, Ohio. Tests were performed using different maneuvers such as J-Turn, slowly increasing steer (using steering controller), lane change, double lane change, and constant radius turn. Variables such as lateral acceleration, yaw rate, roll rate, brake chamber pressures, steer angle, vertical wheel displacements and ESC signals were collected during the tests. Tests were done at different speeds. The vehicle speeds were increased in steps of 5 mph (8 kph) in successive tests until wheel lift occurred or there was a loss of directional control. The tests were carried out with tractor and trailer ESC systems switched OFF and ON alternatively to get the following four combinations.

Table 2: ESC ON/OFF combinations

	Tractor ESC	Trailer ESC
Combination 1	OFF	OFF
Combination 2	ON	OFF
Combination 3	OFF	ON
Combination 4	ON	ON

Three different load conditions were employed in the semitrailer while testing:

1. Lightly Loaded Vehicle Weight (LLVW)
2. Gross Vehicle Weight Rating (GVWR) with low Center of Gravity (CG) height
3. Gross Vehicle Weight Rating (GVWR) with high CG height

The LLVW condition is represented by the empty trailer fitted with outriggers on either side. Concrete ballast blocks each weighing approximately 2000 kg were used to obtain the GVWR conditions. The weights were distributed such that one set of blocks was placed at the front of the trailer and another at the rear. The increase in center of gravity (CG) height was obtained by placing the concrete ballast blocks on top of spacer blocks,

which approximately weighed 225 kg each. The blocks were secured by load rails which were installed in the trailer.

Table 3: Truck Loading

	Weight of Ballast Stacks		Combined Ballast CG location	
	Front stack (kg)	Rear stack (kg)	Height from trailer floor (mm)	Distance from front of trailer (mm)
Low CG	9,993	8,950	297	6,744
High CG	10,464	8,650	1,250	6,949

Table 4: Total Truck Weight

Load Condition	Total Truck Weight (kg)
LLVW	17,364
GVWR with Low CG	35,525
GVWR with High CG	35,698

DATA ANALYSIS

The data from tests in which either only the Tractor ESC was ON or both Tractor and Trailer ESC systems were ON were analyzed to study the response of the Tractor ESC. The ESC system of the tractor had both RSC and YSC features in it. They control the brakes as well as the engine throttle. So a total of four control channels of data were recorded for the ESC systems: RSC controlled braking, RSC controlled engine throttle, YSC controlled braking and YSC controlled engine throttle. Data from the tests done on the dry asphalt surface were used for this research. The ESC activation signal recorded was a pulse beginning at the time the ESC system activated and ending at the time the ESC system deactivated. The activation signals from different tests were overlaid on the lateral acceleration plots of the corresponding tests. As the pulse signal shows the time at which the ESC system is activated and deactivated, its intersection with the lateral acceleration curves gives the values of the variable at the time of ESC activation and deactivation.

The RSC function of the ESC system was observed to activate once the lateral acceleration exceeded certain threshold values. It was observed that on activation, the RSC first cuts the engine throttle and then applies braking. During the tests, the YSC functionality was not activated. This could be primarily due to the fact that the test data considered were from a dry surface where the friction coefficients between the wheels and the road surface are high enough to maintain traction and hence the chances of loss of directional control are less. But high CG coupled with high lateral acceleration is enough to initiate a rollover on high friction surfaces which causes the RSC function of the ESC system to activate in the above tests. The purpose of this research is to create an RSC system for the tractor and these data are sufficient for that purpose.

TEST DATA

The steering controller makes it possible to repeat the tests with the same steering input. This makes the results of these tests more uniform as compared to the results of the tests where drivers manually steered the truck. Hence, the tests with steer control were studied in-depth. The data collected during one such test (Test No. 936) is shown in this section. The test was conducted with GVWR loading at low CG height. The maneuver is a Slowly Increasing Steer and the target vehicle speed was 35 mph (56 kph). Figure 1 shows the path of the vehicle during the test. A GPS receiver was mounted on the tractor and the variables 'Eastings' and 'Northings' are the measured values of the tractor's X and Y positions.

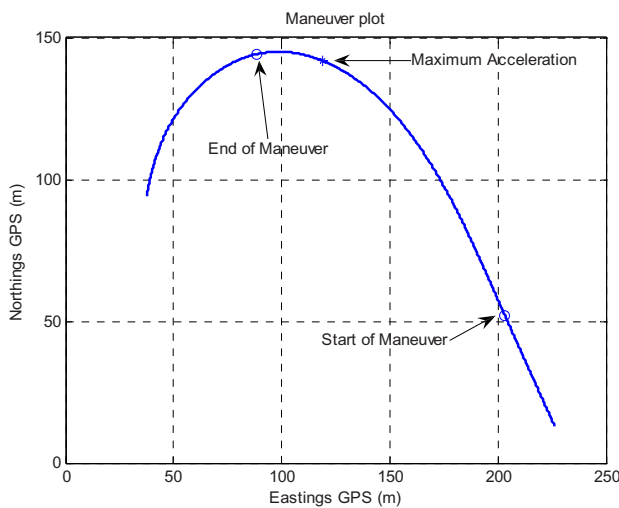


Figure 1: Path of Vehicle Motion

The test was conducted at a constant speed with slowly increasing steer as specified by SAE J266 standards. Once the vehicle attained a constant speed of 35 mph (56 kph), the maneuver was begun by triggering the steering controller. A constant steering rate of 13.5 deg/s was maintained by the controller for a period of 10 seconds.

Figures 2 and 3 show the steering wheel angle, velocity and the lateral acceleration values with the ESC activation signal superimposed on them to show the values at which RSC activated. The two plots show the RSC first deactivating the throttle followed by RSC activating the brake indicating the sequence of events as they occurred.

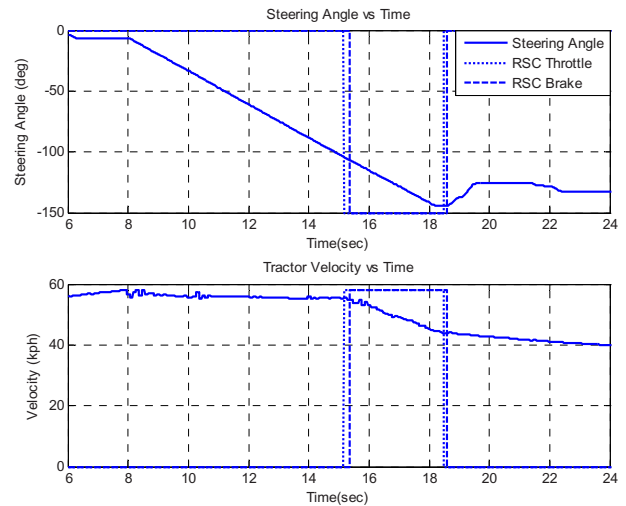


Figure 2: Steering Wheel Angle and Truck Speed as Functions of Time

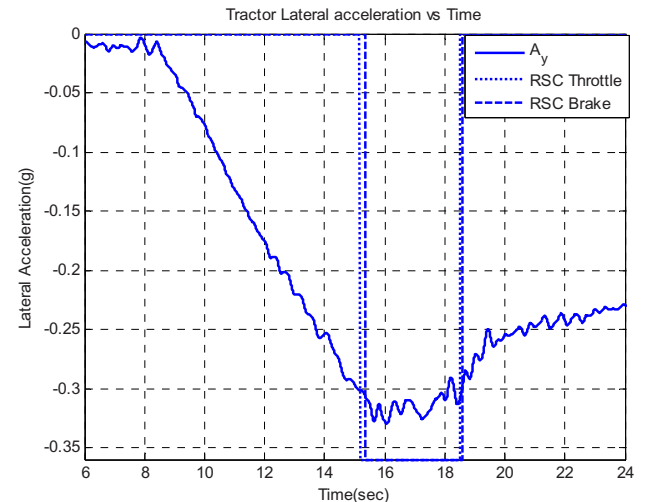


Figure 3: RSC Activation Signal Overlaid on the Lateral Acceleration Plot

The response of the RSC system was also studied by observing the brake chamber pressures of the individual wheels of the tractor and the trailer. This gives an idea of how the RSC system selectively applies braking on the wheels. The tractor RSC was also observed to brake the trailer as shown in Figure 4. Since the tractor is the leading unit, its lateral acceleration is used by the tractor RSC to brake the trailer as a preemptive measure and also to slow down the entire vehicle. Note that 100 kPa is equal to 14.5 psi.