

Simulation-based Certification of ESC Systems for Passenger Vehicles in Europe

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ABSTRACT

In today's automotive climate, the tendency of an increasing number of vehicle model variants offered is coming to a head with the growing demands for safer vehicles. New legislation now ensures that the safety improvement by the fitment of stability control systems is certified for each new vehicle. Beginning year 2012, all new cars to be sold in the European Union have to be equipped with ESC, and as means to test performance, a new supplement to ECE R13 requires that the Sine-with-Dwell test be passed.

As a result, OEMs have to handle the task of demonstrating that all their vehicles meet homologation requirements. With such a range of variants possible in each model, this can lead to an enormous quantity of testing. However, for the first time, ECE R13 allows homologation to be undertaken by test-supported simulation, and it is now possible to transfer more and more of this work into CAE.

This paper describes the results of a project executed at General Motors Europe (GME) in cooperation with Applus IDIADA to prove, document and ensure that it is possible to simulate the Sine-with-Dwell test as the base for ESC certification. Based on extensive static and dynamic tests the validity of a vehicle model together with a brake controller and hydraulic model are demonstrated. With several steps of model correlation it is ensured that all model components are understood in detail, so that it is possible to vary model parameters maintaining the validity. Thus, it is possible to cover the complete range of vehicle variants.

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INTRODUCTION

Since in 1997 Swedish journalists flipped a well-known car during a double lane change maneuver called Elk-test, this kind of test became a common standard (ISO 3888-2) to examine vehicle rollover stability. This led to an increasing market penetration of Electronic Stability Control Systems (ESC) [1], since these systems significantly enhance vehicle dynamics stability [2]. The effectiveness of ESC has been confirmed by numerous national and international studies, which show that ESC has a positive impact on 25% of car accidents involving personal injuries and at least 35% involving fatalities [3]. In Germany, about 80% of all newly-registered cars are currently equipped with ESC. However, the situation cannot be considered satisfactory because this figure drops to only about 60%, if the average for all EU countries is considered. Since the European Union has announced challenging plans to halve the number of road

deaths on Europe's roads by 2020, a new supplement to ECE 13-H regulation has been released which makes ESC systems compulsory from a given point in time.

Beginning with a short excursion into the EU certification legislation which is based on the so-called "Sine-with-Dwell"-test, this paper describes the complete process of simulation-based ESC certification. A similar approach has already been applied successfully to the domain of heavy trucks [4]. For passenger cars, the approach described here is first-in-industry. One central element is a validated simulation environment for vehicle dynamics and chassis controls [5]. To prove its validity, one extensive section of this paper is dedicated to the validation of the simulation environment, using an Opel Meriva as exemplary vehicle. Coupling this high quality simulation model to a real ESC Electric Control Unit (ECU) in a Hardware-in-the-Loop (HiL) simulator allows the execution of all relevant driving

maneuvers which are used for ESC testing and certification in simulation. A separate section of this paper describes the results of the “Sine-with-Dwell” test in detail and shows how these results can serve a certification authority (Technical Service) as a basis for their type approval.

CERTIFICATION PROCESS ACCORDING TO ECE R13-H

On November 11, 2009, a new supplement was added to ECE Regulation 13-H by the European Parliament [6]. It orders all new passenger cars of classes M1 and N1 seeking a type approval to be equipped with Electronic Stability Control Systems (ESC) from November 2011. For already existing variants, ESC is mandatory from November 2013. Similar requirements have been provided for truck vehicles, touring coaches and commercial vehicles above 3.5 tons. Not only the EU, but also legislators from other regions all over the world are in the process of defining regulations for the mandatory use of ESC in passenger cars or have already done this (e.g. NHTSA FMVSS-126 regulation).

REGULATORY DEFINITIONS AND TEST REQUIREMENTS

According to ECE R-13H, ESC is defined as a system that “is capable of applying braking torques individually to all four wheels and has a control algorithm that utilizes this capability” and “is operational over the full speed range (above 20 km/h) of the vehicle, during all phases of driving including acceleration, coasting, and deceleration ...”. The performance of the vehicle stability function has to be demonstrated under specified conditions to the Type Approval Authority or Technical Service. One important test to assess lateral stability is the Sine-with-Dwell steering maneuver [7] which is driven using a steering robot. The respective steering wheel angle characteristic is shown in Figure 1.

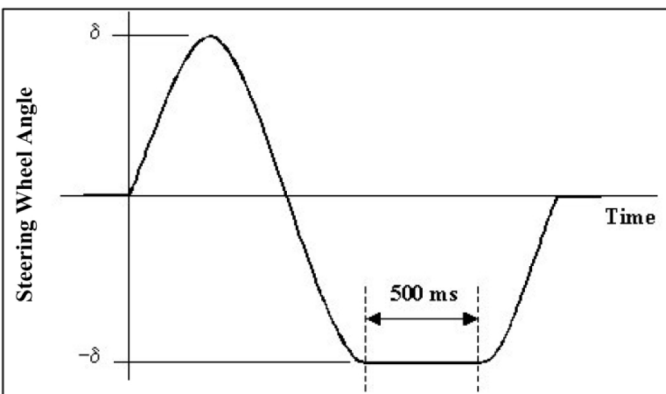


Figure 1. Steering wheel angle in Sine-with-Dwell maneuver

In addition to demonstrating the functionality of the ESC by a real driving maneuver, ECE- R13H provides the

opportunity to use computer simulations [6]: “Where a vehicle has been physically tested [...], the compliance of versions or variants of that same vehicle type may be demonstrated by a computer simulation, which respects the test conditions [...] and the test procedure.” The variants may differ for example in body structure, powertrain, tires, masses or load conditions.

REQUIREMENTS FOR THE USE OF SIMULATION TOOLS

The regulation explicitly allows the use of computer simulations to prove the performance of the ESC once the required real world test involving the Sine-with-Dwell maneuver has been performed successfully on one prototype car. This option reduces the amount of real testing variants enormously and accordingly the costs of expensive prototype cars. However, there are strict validation requirements including verification of the modeling by means of comparisons with real world tests. Also, the simulation tool must be approved by the Technical Service. The simulation method has to reflect the main factors which influence the lateral and roll motion of the vehicle. A typical model should include the following vehicle parameters in an explicit or implicit form:

- Axle/wheel
- Suspension
- Tire
- Chassis/vehicle body
- Powertrain/driveline, if applicable
- Brake system
- Payload

There are two possibilities of adding the ESC functionality to the simulation model. One is to integrate the real Electronic Control Unit (ECU) with the vehicle simulation model in a Hardware-in-the-Loop configuration (HiL). The alternative would be to implement the ESC function using a simulation model of the ESC controller coupled to the vehicle model in a purely math-based environment called Software-in-the-Loop simulation (SiL). This paper focuses on the HiL approach.

SIMULATION ENVIRONMENT AT GM EUROPE

To ensure a high-quality vehicle dynamics simulation, GME Engineering established a virtual tool chain to generate and parameterize vehicle dynamics models starting from a Multi-Body-Simulation (MBS) model which is - since it is not real-time capable up to now - transferred into the IPG CarMaker real-time environment for the HiL application [5].

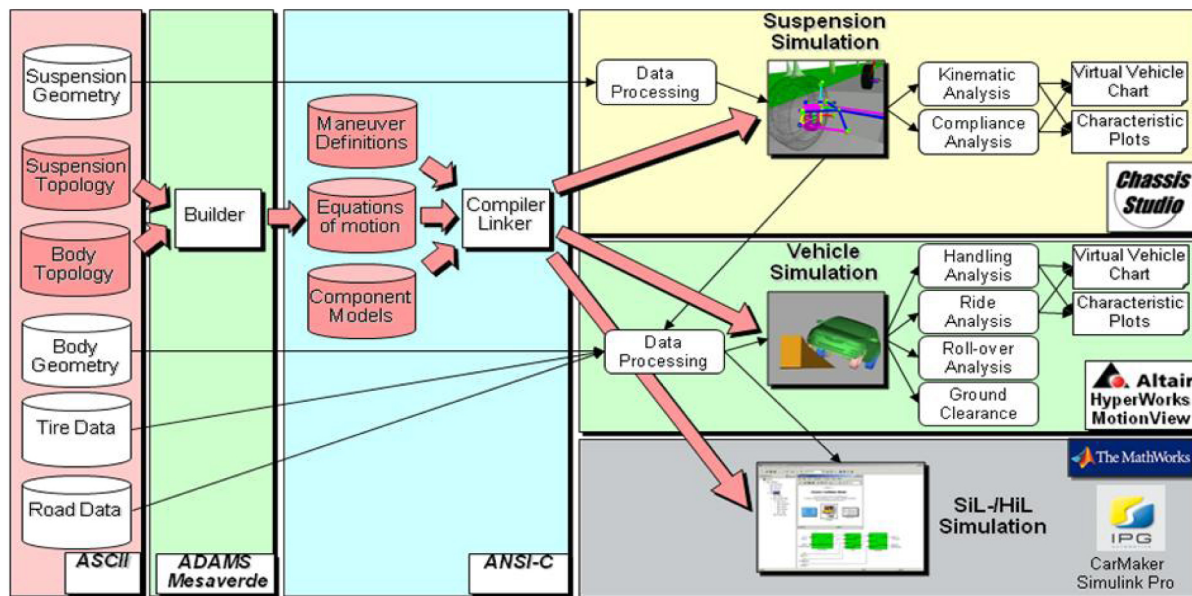


Figure 2. GME multi-body vehicle dynamics simulation environment

MBS SIMULATION

At the first stage of the virtual tool chain a Multi-Body-Simulation model is built based on the topology of the suspension given as a draft or a verbal description (see Fig. 2). Using either an analytical solver (Mesa Verde) or a numeric solver (Adams) the system of equations of motion is generated. Subsequently models of the springs, the dampers and the bump-stops as well as the bushings are added to this set of equations. These component models are defined in the Virtual Model Components (ViMC) library. Thus, the component models are consistent for all vehicle models.

In the next step, the input maneuvers (loadcases) describing the axle motions are included. The loadcases for suspension kinematics and compliance analysis, for static and dynamic loads prediction and also for chassis and wheel clearance analysis are standardized and harmonized within GM global vehicle dynamics community. To perform vehicle ride and handling analysis a rigid body model of the vehicle body, models of the tires and wheels, the road, the powertrain, the brakes and the steering system (including power-steering characteristics) are added to the suspension models.

The tire model is selected depending on the requirements of the use case. E.g. for vehicle handling performance with chassis control systems, which is the use case for the certification according to ECE R13-H, a real-time version of the IPGTire, the RealTime Tire, is in use. This model is based on digitalized tire characteristic curves. Unlike the Pacejka model the characteristic curves are not fitted to a “magic formula”, but they are converted directly from a text file in TYDEX format into a binary format. The tire characteristics are measured on a tire test rig (e.g. outer roller drum test rig) with quasi-static and dynamic measurements varying the

load, tire pressure, camber, slip and slip angle. The resulting tire characteristic curves are tuned or validated with road test data, which include measured wheel forces and moments. The corresponding wheel angles and positions are either determined by simulation when using a vehicle with well-known axles or also have to be measured during the road test.

Finally the maneuvers (loadcases) for vehicle ride and handling analysis are included. The analysis of the vehicle ride and handling performance is done using standardized loadcases, e.g. steady-state cornering, step steer or double lane change.

The structure of the multi-body-simulation model is held modular, parametric and scalable. The model structure is kept apart from data. Following the single-source-principle, model structure is stored and maintained centrally, whereas model diversification is done through vehicle-specific parameterization of the model. All subsystem models are tested and validated independently from each other. According to the given loadcase and the required model accuracy the overall multi-body model includes between 15 and 150 degrees of freedom.

CREATION OF VIRTUAL VEHICLES

The decision on the complexity of the vehicle model to be used for ride and handling analysis depends on the loadcases to be investigated. For ride analysis as well as for transient vehicle handling analysis in the linear range of lateral vehicle dynamics without chassis control systems active ($< 0.4g$ lateral acceleration) the high resolution vehicle model is used.

To run simulations in the upper, nonlinear range of lateral vehicle dynamics ($> 0.4g$ lateral acceleration) with the chassis control systems in-the-loop, efficient real-time capable vehicle subsystem and component models are needed. Since the vehicle data set is to be kept consistent

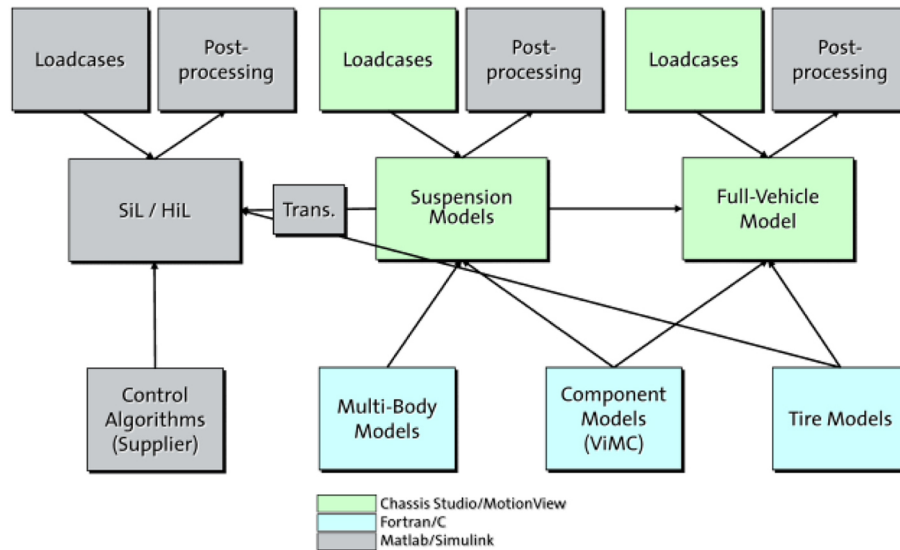


Figure 3. GME tool chain to create virtual vehicles

across the tool chain, the multi-body representations of the suspensions are transformed to multi-dimensional look-up tables (see Fig. 3). These look-up table based models of the suspension kinematics and compliances are integrated in the IPG CarMaker simulation environment used for SiL and HiL simulations of the chassis control systems.

The mentioned tool chain allows a creation of a large number of valid parameter sets (virtual vehicles) for the HiL simulation of closed loop driving maneuvers. However, structure-wise, all models and sub-models are constantly validated to ensure the overall simulation quality of the completely virtual vehicles.

HARDWARE-IN-THE-LOOP-SIMULATION (HiL)

Based on a GM worldwide decision, since 2004 all Hardware-in-the-Loop simulators are based on dSPACE hardware. In order to keep the best practices of almost twenty years of simulation experience, GME Engineering decided to continue to use the IPG CarMaker/HiL software environment on the dSPACE platform. With some changes in the dSPACE runtime environment the IPG CarMaker runs in the same way as it would run in Software-in-the-Loop or on IPG proprietary hardware. Those minor changes do not have any side-effects on other applications running on the hardware. However, a direct file access from the host (i.e. real-time) computer onto the client computer, allows for direct parameter changes via the CarMaker main GUI or via scripted access. The IPG CarMaker/DS makes use of multithreading on the RT-systems, which enables continuous real-time operation. Thus, the communication with the ECU never stops, neither while downloading new vehicle model parameters, nor during measurement data exchange (e.g. for real-time 3D-animation).

Figure 4 shows GME's HiL simulation environment which is used for the vehicle performance simulation of the chassis control systems in the Opel Meriva. In the HiL simulator, the simulation model of the Meriva is coupled to the ESC ECU (Bosch ESP 9.0).

In order to maximize the output of all HiL systems, a GME proprietary Test Automation allows for 24/7 usage of the HiLs. It contains features for a remote configuration of the CarMaker environment (i.e. vehicle, driver, road parameters) as well as automated execution and evaluation of a large set of virtual driving maneuvers. Finally, an automated report, generated by the Test Automation, shows the test results in detail. The HiL environment is parameterized by validated model data derived in the following section.

VEHICLE MEASUREMENTS

TEST VEHICLE AND MEASUREMENT EQUIPMENT

The vehicle used for the investigation was the Opel Meriva, a five-door mini MPV, with the following characteristics: wheelbase of 2640mm, front wheel track 1490mm and rear track of 1505mm. Typical for this class of vehicle, it is equipped with McPherson front suspension and a twist beam at the rear. The steering system is an EHPS (Electro-Hydraulic Power Steering) and Electronic Stability Control (ESC) is fitted as standard equipment.

To prepare for the model build and validation work, first it was necessary to complete a large vehicle test program to characterize both - system and vehicle performance. As part of the handling test program, one of the most complex vehicle instrumentation configurations was installed from which an unprecedented level of vehicle data was recorded at IDIADA.