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# Advanced Methods in Crash Safety Testing - Active Lateral Intrusion Simulation

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**Abstract.** This work is to give an overview of currently used methodology in the field of passive safety, ie. crash tests. There are two types of crash tests (mandatory, consumers) with many setup scenarios. As the OEMs aim to cover all legislative and get top score in consumer tests, there is a high pressure on safety. So far the physical crash testing has been mainly done on full vehicles.

## Introduction

Main idea is to come up with an improved testing methodology of simulating crash tests. It is supposed to decrease development time, while increasing volume of work done and variability altogether with cost reduction. Such an approach has been allowed by a new catapult system DYCOT that was opened by TÜV SÜD Czech in Mladá Boleslav last year. It enables an advanced approach to performing side crash physical testing by using sled test and unique "Active Lateral Intrusion Simulation" (ALIS).

The basic principle will be described as well as first steps to the overall results. ALIS has to be designed and simulated first before physical validation and testing will take a part.

Such a combination of DYCOT and ALIS presents unique testing capabilities at least within the Europe region and should significantly improve restraint systems tuning and hence improve biomechanical loads in general.

## Crash tests

The principle of the crash test is to understand mechanics, kinematics and dynamics of the impact itself. With first crash tests in the second half of the last century, they have assessed structural behaviour of the vehicle only with output parameters such as deceleration and intrusion. Later on the effect of the crash on human body has been put in front and so the first dummies have been developed. Nowadays there are many types of dummies. Each of them represents different "human body" and allows different biomechanical parameters to be measured and it is intended for different crash event.

### Mandatory and consumer crash tests

Mandatory tests have been established by governments to ensure minimal safety and all vehicles have to meet their criteria. Each country/region has its own tests (e.g. EU, USA, China,…), nevertheless they differ only in several cases. The base is pretty much the same everywhere and so is the occupant protection. Mandatory test have two results – pass or fail. Overview of the crash tests around the world is shown in Figure 1.

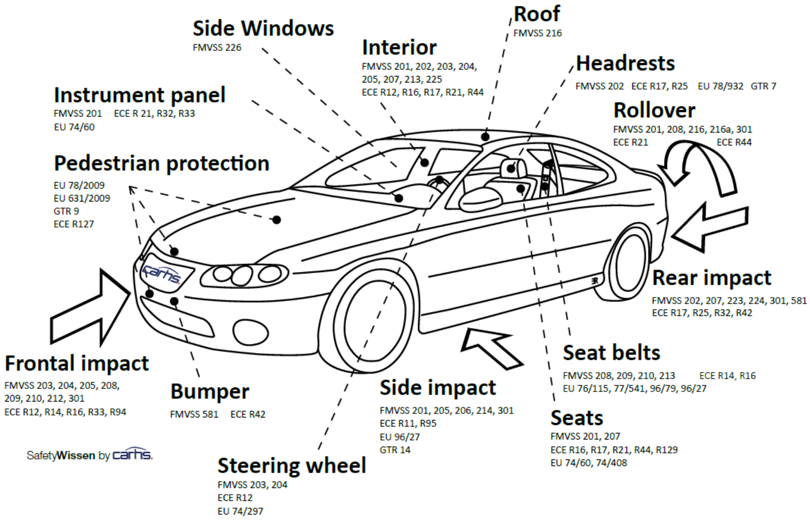


Fig.1 Overview of crash tests [1]

Consumer tests have been additionally established in order to compare cars among OEMs and so push them to the improved safety through better score. They are usually stricter than mandatory tests. The results scale is different to mandatory tests and it uses stars, when 5-star is a top score. The score is based on car safety performance during all types of crash tests, presence of other safety features (e.g. seatbelt reminder) and others.

The main objective of the crash tests is to assess car primary structure performance in terms of injury risk. Main criteria are biomechanical loads that apply to human during crash. The whole complexity of the system is assessed via parameters (biomechanical loads) measured on several parts of body. These parts are as follows (standard for ECE legislation and EuroNCAP):

- Head
- Face
- Neck
- Chest
- Abdomen + Pelvis
- Spine
- Lower extremities

### Restraint systems

Restraint system is a passive system in car that does not require any action from driver or passenger to get it work. There are two main sub-systems:

- Airbags
- Seatbelts

Airbag is a vehicle safety device that is based on rapidly quick inflation and deflation. It consists of flexible bag from fabric, inflation module, sensor and soft cushion. When the vehicle crashes with sufficient severity, sensor will trigger inflation module and the cushion is inflated. This inflated cushion decreases head acceleration and generally softens the head impact pulse and absorb some head kinetic energy. It is important as it does not allow the head to come into the contact with steering wheel and dashboard (front crash) and other structural parts, including trim (side crash).

Seatbelt is a safety feature that "controls" movement of the pelvis and torso. There are many types of the seatbelts (2-point, 3-points, 6-points, etc.) but the common one is 3-points lap belt. It has got two additional features. Load-limiter triggers when the maximum load in seatbelt is reached, it slightly releases a seatbelt and engages again. One could call this principle as ABS for seatbelts. Pre-tensioner is triggered just like the airbag by a sensor, but this sensor derives the severity of the crash event. It measures pressure drop when closing to another object and ensures that in the early stage of the crash the body will be tightened to the seat via pre-tensed seatbelt. This reduces further injury risk due to excessive body motion.

There are some others types as well but there are not that widely used compared to airbags and seatbelts. All restraint systems are very important for minimizing the injury risk during crash and so they will be included in further simulations and testing.

## New approach

- **Current status**

At the moment airbags setting has been found as very important, but difficult. Simulations have shown certain level of accuracy, but for correct validation many expensive crash tests have to be carried out. In the whole world, the absolute majority of tests have been done with full vehicles. The procedure is sketched in Figure 2.


Fig.2 Current development approach

That means expensive and time-consuming. With increasing testing requirements, people have tried to find an alternative approach that would offer a sufficient level of predictability and accuracy with time and money reduction. Physical testing of sub-systems has been on market for a while, but it has not been considered to be used for side crash that much.

There has been a request on global market to develop such a testing device and method to incorporate all mentioned above. Such a device should be able to test sub-systems and also simulate side acceleration pulse. Usually catapult that is able to develop precise negative pulse that imitates side crash acceleration has been used. As it has been known, sled tests have been covering mostly front and rear crash scenarios. Usage of sled test for side impact is rather rare and it is not the main task of it.

There are several test labs around world that attempt to simulate side crash via sled tests. It consists of sled platform and additional system for lateral loading – pushing from side. This method is rather new. Currently one hydraulic cylinder is being used to imitate door intrusion mechanism.

### DYCOT

TÜV SÜD Czech has recently invested a large sum to test lab equipped with sled system (catapult) – DYnamic COmponent Testing (DYCOT). The capabilities of such test device have been significantly increased by adding Advanced Lateral Impact System (ALIS) into serie, right next to the sled platform. It uses up to 6 hydraulic cylinders in order to correctly simulate the door intrusion kinematics during the side crash. It enables one to use only small part of the car together with dummies and restraint systems and carry out simulation of the side crash with focus on restraint system and biomechanical loads.

The system may seem as a "train of trolleys". The driven sled trolley is mounted to the main hydraulic system that generates the main acceleration pulse. ALIS is mounted on the separate trolley, attached to the sled one. The whole structure is shown on the Figure 3, where main components are identified. The lateral system consists of additional hydraulic system, several hydraulic cylinders, linear guiding system and "impact break-in structure".

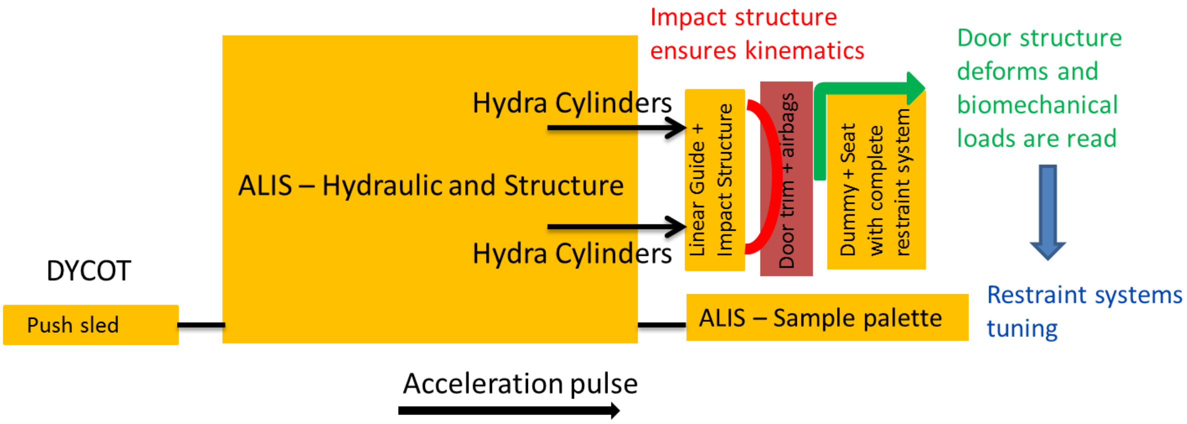


Fig.3 DYCOT + ALIS concept

As this equipment is supposed to cover and be useable for most of the typical cars, it has the ability to move all cylinders within a working space. This forms a boundary box that has been overlaid by typical car sketches as shown on Figure 4. Note that the space covers area between front driver and rear passenger.

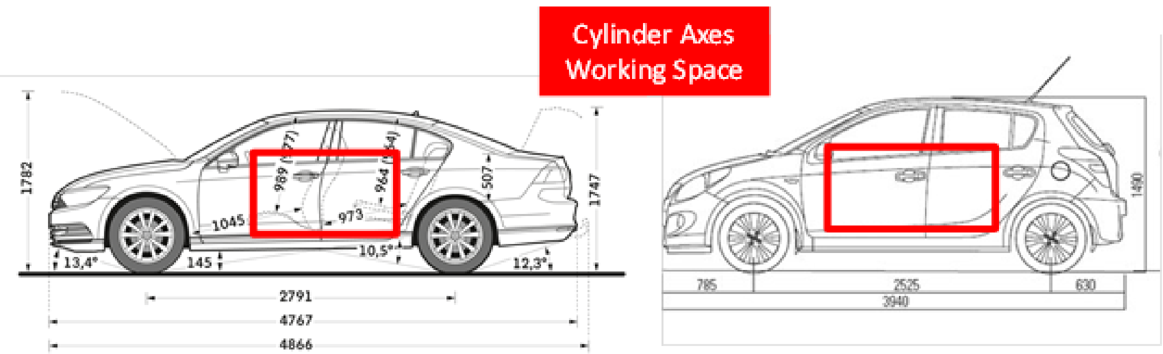


Fig.4 Typical car vs ALIS and MDB (sketch) [2,3]

This is very important as according to the latest ECE and EuroNCAP standards, the rear passenger will be evaluated as well. So far all test methods and systems have been focused only on the single passenger, mainly driver. ALIS presents a unique opportunity to capture also interaction between driver and front passenger and also between rear seat passengers. It has not been assessed so far and offers a great way to evaluate a lot of new data, biomechanical loads and mechanisms within one test run or simulation.

## Principle of ALIS

The basic principle is to accelerate the sled with ALIS attached according to the real side crash pulse while the cylinders push forward through linear guide into the "impact structure". It should then cause exactly the same intrusion and kinematics of the door system, ie. biomechanical loads (=replication of the physical test). The source data will be extracted from full vehicle crash test and sled test Finite Element (FE) simulations.

The main idea is to perform simulations before the physical testing loop to ensure the correct kinematics and structural behaviour reflect physical test. The simulation would determine parameters such as amount and position of used cylinders; timing, shape and magnitude of the cylinder pulses. These will be then used for the physical test of reduced model. The method is unique due to its limitless options of simulations. It will save time, money and help engineers with restraint systems tuning. Currently the process of tuning side, curtain and head airbags is extremely time-consuming and expensive (painful). The approach is based on using only part of a car and it is a combination of physical and virtual methods. It is clear that every vehicle will require unique set of input parameters as well as impact structure.

## Methodology

The whole process starts with prototype and is shown in Figure 5. When the first one is built and crashed, biomechanical loads are recorded. Following that correlation of FE simulation is the next step. Output is to be biomechanical loads, intrusion and kinematics of important structural parts such as doors, A- and B-pillars.

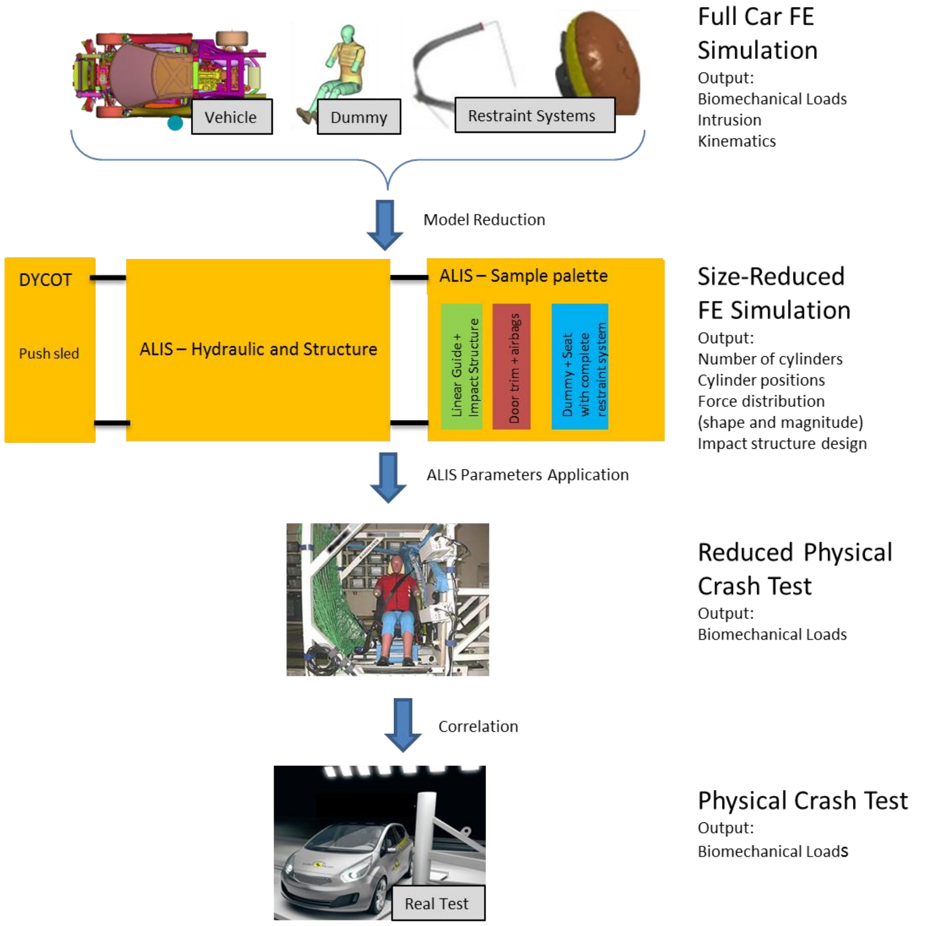


Fig.5 Real crash to ALIS reduction procedure [4,5]

Size reduction of FE model comes next. The most important outcome of this phase is determination of the ALIS settings. This includes number of cylinders used, their timing and also design of the impact structure. Amount of input parameters is countless.

**Stages and partial objectives**

Complete process covers many intermediate steps that need to be met in predefined sequence. The complex problem has been split into several major steps as follows:

- Take over initial complete side crash simulation of virtual car – pole strike / barrier (from OEM)
- Model size reduction and evaluation of biomechanical loads
- Creation of ALIS virtual model and setup (kinematics, interactions,…)
- Initial determination of physical setup input parameters of ALIS (@biomechanical loads)
- Correlation of physical and virtual test
- Final assessment of the setup for ALIS and its definition
- Successful physical test


There are several available approaches, but main two have been selected also known as “Design of Experiment” (DoE) and Step-by-Step iteration with subsequent physical correlation.

Design of experiment is advanced mathematical approach, where there are ranges of input parameters. Based on measured responses, the mathematical n-dimensional response surface is created. Such a method has been used especially for sensitivity and robustness studies and would reduce number of runs and predicts multiple results based on input parameter combination as shown in Figure 6.

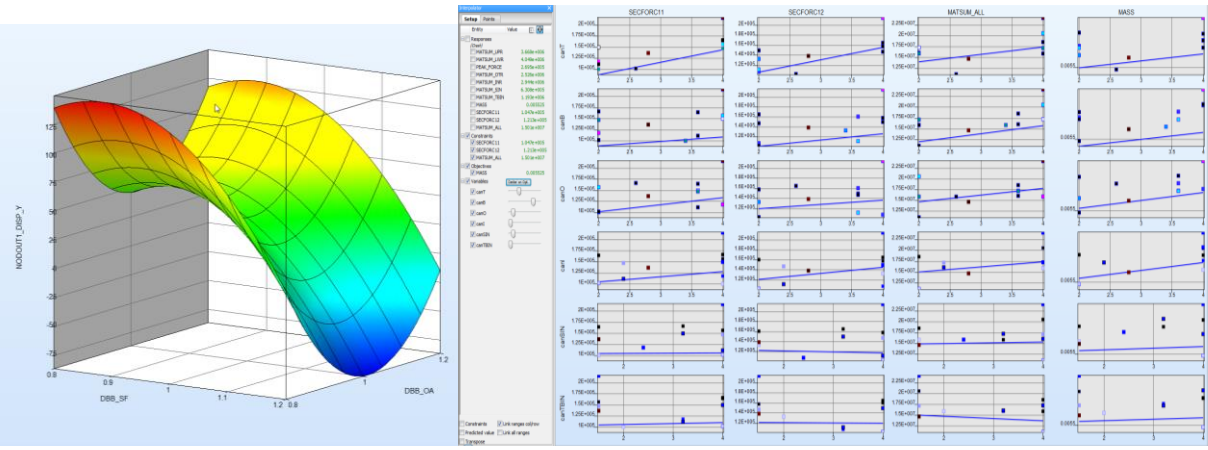


Fig.6 “DoE” Response surface (left) and sensitivity study (right)

Step-by-step iteration presents traditional approach where every change of parameter is being investigated and therefore know-how base is built. The complete process, including iteration loop, is shown in Figure 7.

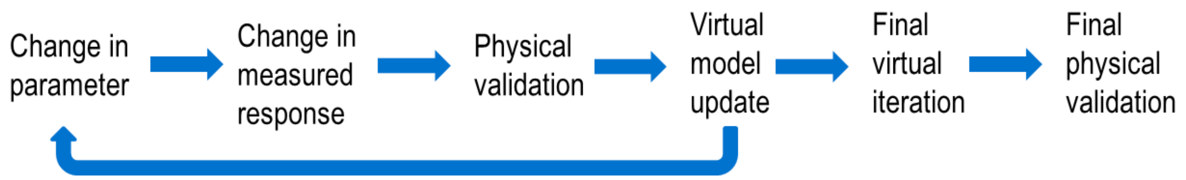


Fig.7 Step-by-Step iteration scheme

Ultimate idea of both methods is to be able virtually reflect and simulate real physical behaviour of the system. Due to many unknown variables this task represents very complex problem that needs to be understood and patiently tuned.

## Conclusions

The main objective is to develop a virtual method that would allow reducing full crash into sled crash via ALIS, defining complete ALIS setup and give highly accurate results, while reducing costs.

This new approach to such a problem size is a unique in at least the whole Europe and has never been applied before in such scale. It combines physical and virtual testing and should lead to sufficient and efficient support in terms of restraint system settings. It should bring reduced costs, decreased time of the product development cycle, increased predictability in early stage of the project and quick and cheap tuning of restraint systems.

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