New advanced methods in side crash testing

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Abstract

This work follows up the previous work regarding the used methodology in the field of passive safety, ie. crash testing. The work is based on experience gained in the Active Lateral Impact Simulator (ALIS) project and describes complete process. As the mechanical and geometrical parts have been already discussed in previous work, the main focus has been shifted to the fine-tuning of the boundary conditions and loading of the system in order to ensure correct biomechanical loads. It has been already decided that only pole strike is of interest and therefore the barrier strike will not be assessed and developed.

This work is to give an overview of current methodology and subsequently propose a new advanced approach of combined virtual and physical testing. The main idea is to reduce development time and associated costs by using sled testing which used to be used mainly for physical simulation of frontal crashes. Simulation of side crash in sled environment is not a brand-new topic, but certainly very complex one. This method is not really used on regular basis especially due to predictability issues and low accuracy. This work presents new approach of combination both virtual and physical testing. The whole process starts with full crash simulation, goes through conversion of virtual model to reduced sled model, sled testing and finally is wrapped up with full vehicle crash.

The new method uses mathematical-statistical method Design of Experiment, that offers many benefits for the physical test setup and furthermore the general overview of the sensitivity of system behaviour.

Keywords: crash test, finite element method, design of experiment, biomechanical loads, DYCOT, ALIS

Motivation

Due to large amount of physical crash tests there is a high demand on reducing the problem size. That would allow quicker and more accurate finite element correlation, restraint system tuning (airbags, seatbelts) and more convenient dummy positioning.

The main objective of the thesis is to develop virtual method of real side impact sled test with corresponding biomechanical loads that would reflect the full vehicle crash test. It should also shorten necessary development time and improve predictability and accuracy of both physical and virtual testing and hence significantly reduce costs associated with vehicle development. Finally, the output would enable complex tuning of restraint systems which are currently difficult.

Outcome of this work will be ALIS test setup and sensitivity study of the whole system behaviour.

In order to reach main objectives, a new approach that uses virtual method and mathematical apparatus that would determine complex system setup has to be suitably implemented. It may use an advanced mathematical model for results evaluation and sensitivity and robustness studies.

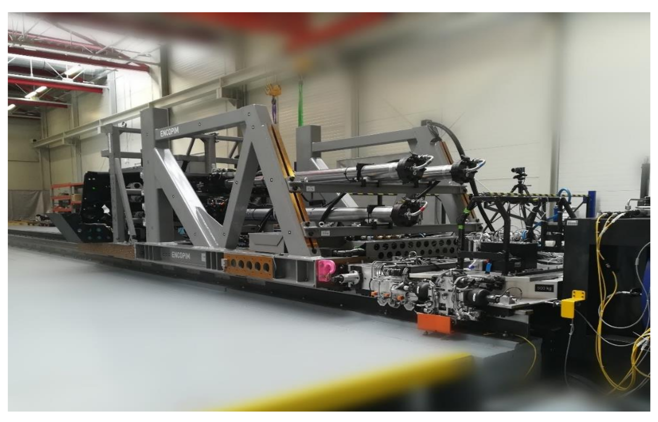
Method

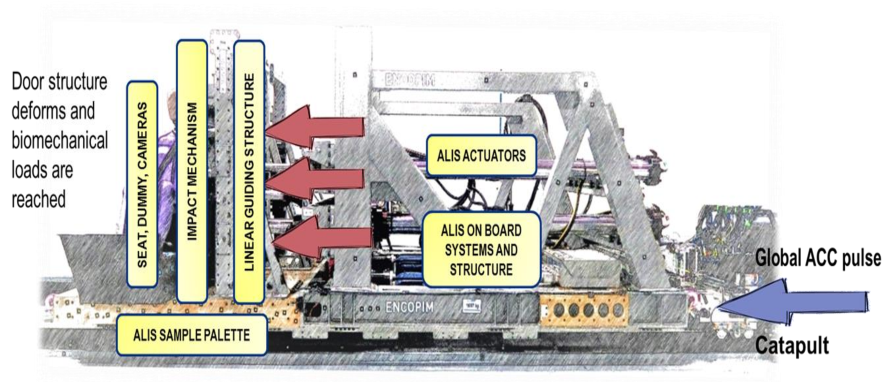
DYCOT

TÜV SÜD Czech has recently invested a large sum to test lab equipped with sled system (catapult) – DYnamic COmponent Testing (DYCOT). Sled test system consists of sled with grid holes and pusher sled, where all electronics and measurement equipment is mounted as also shown on figure below. The pusher sled is being pushed by CSA catapult, equipped with hydraulic piston that can accelerate the sled by up to 90G to total velocity of 100kph with payload of 1000kg. When fully loaded (payload of 5000kg), the piston is capable of accelerating the sled up to 35G. Maximum force is equal to 2.5MN. Maximum acceleration gradient is 14G/ms. It is usually used for frontal crash test where the occupant safety is being tested. It can also be used for testing of crash-landing of any small airplane that would fit in the lab. Latest addition to the service portfolio is battery pack testing for any battery packs up to 1000kg.

ALIS

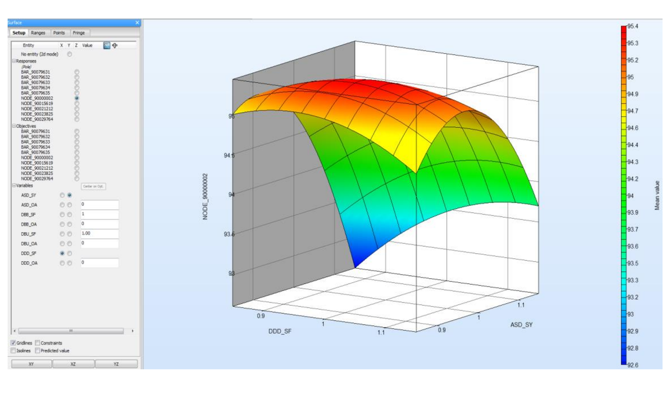
The capabilities of DYCOT sled system have been significantly increased by adding ALIS into serie, right next to the sled platform. It uses up to 6 hydraulic cylinders in order to correctly simulate the door intrusion kinematics during the side crash. It enables one to use only small part of the car 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. The whole structure is shown on figure below, where main components are identified. The lateral system consists of additional pneumatic system directly attached to several pneumatic cylinders, ALIS primary structure and control system, linear guiding system and "impact break-in structure".

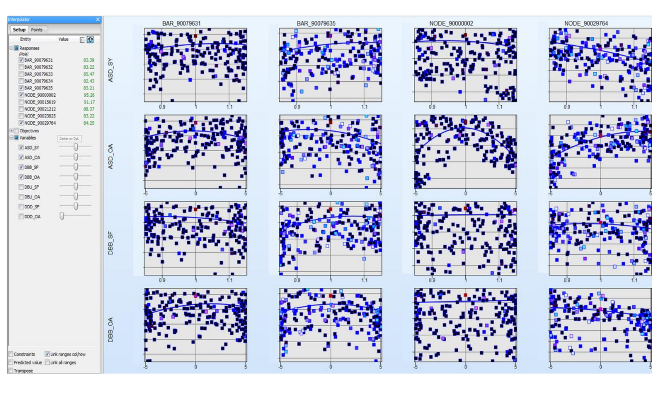




Design Of Experiment (DoE)

DoE approach is not very common in automotive industry and that is also the case in of TÜV SÜD Czech. After reviewing the ALIS process workflow I suggested to use this approach and use the LS-OPT tool. The reason was simple. LS-OPT is known to me for some time and I needed to solve statistical mechanics problem. It took only few moments to figure out solution as I am aware of LS-OPT capabilities.





Objectives

- Stage 1: Take over initial complete side crash simulation of virtual car
- Stage 2: Evaluation of objectives and model size reduction
- Stage 3: Creation of ALIS virtual model and setup
- Stage 4: Initial determination of physical setup input parameters of ALIS via Design of Experiment (DoE)
- Stage 5: Successful physical test
- Stage 6: Comparison of sled test and full vehicle crash

Design of Experiment will be used for sensitivity study of the experimental design. The question is if we apply DoE to the virtual simulations, we expect to get rather detailed insight of the system behaviour and response sensitivities. The idea is to tune ALIS and sled control pulses so well that we will get the biomechanical results very similar to the simulation results of full vehicle.

Results

It is also clear that not all of the absolute values have been reasonably achieved, except for the third thorax rib, but as ALIS is only a sled reduced representation of the full vehicle crash, there is no such ambition. It is obvious that ALIS has got only several actuators that try to generate the same conditions, whereas in full crash there are unlimited "actuators" and therefore it is impossible to replace crashes fully by sled testing only. Sled testing is only an add-on to the full crash testing. This is also why no legislation, nor consumer tests allow purely sled testing. Simply it cannot substitute the full vehicle crash tests.

2nd Iteration loop

The second iteration loop is exactly the same one except for one very important detail. All data input data coming into the simulations are this time extracted from full physical crash of prototype.

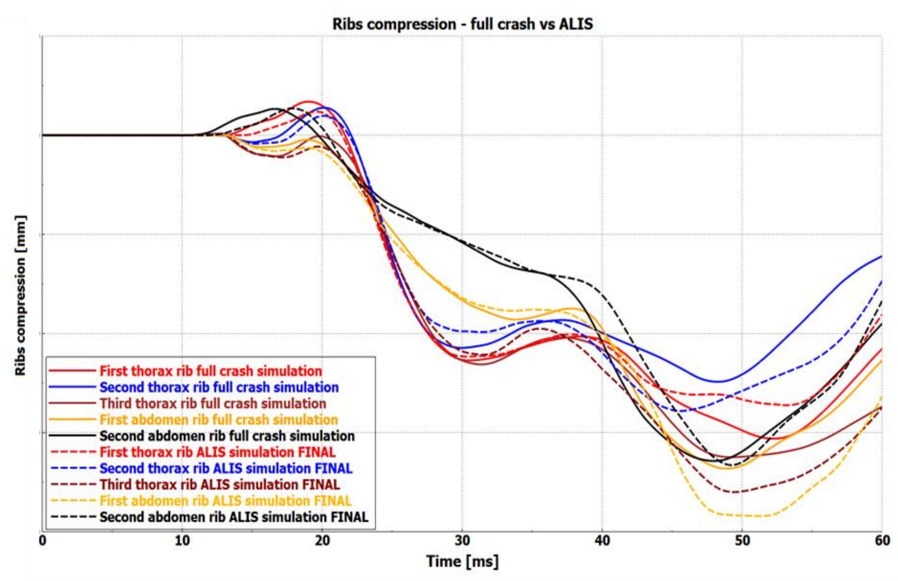
The second iteration loop follows, where simple modification of the impact structure is made to ensure the highest achievable accuracy of the test compared to the complete vehicle crash. In other words, simulations as well as impact structure design in being finally-tuned based on results from prototype crash. The project finishes after development tests, where all ALIS parameters are fixed and customers changes only restraint system settings and evaluates ideal combination of parts and their initial setup (e.g. seatbelt trigger time, airbag vent size, timing)

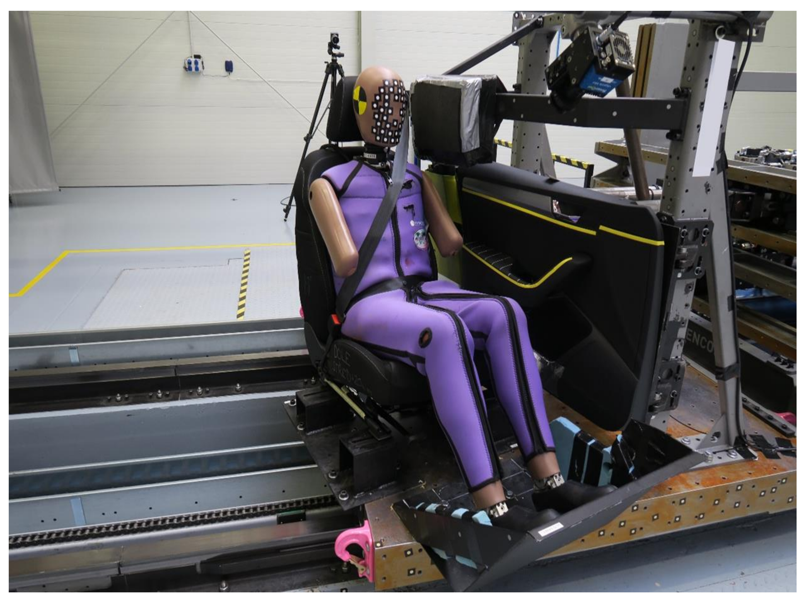
Results for science

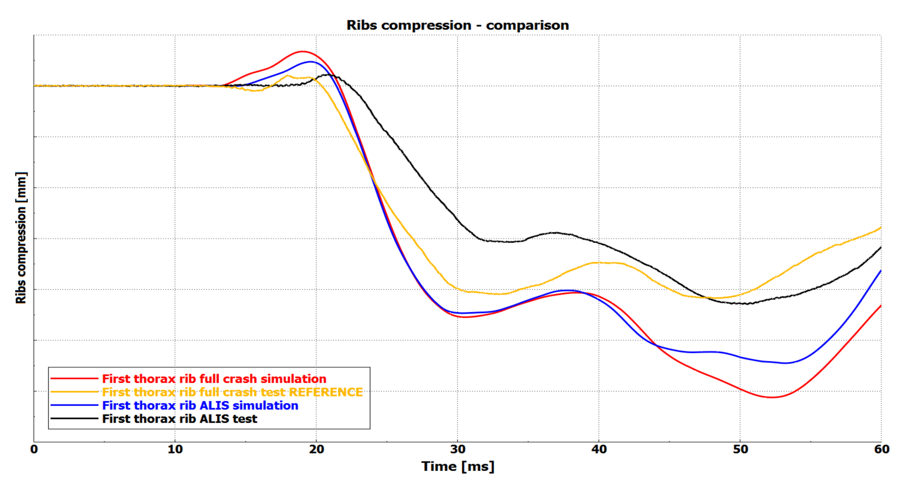
The main accomplishment is combination of newly developed methodology with DoE application into the automotive industry. It opens broad options for other applications.

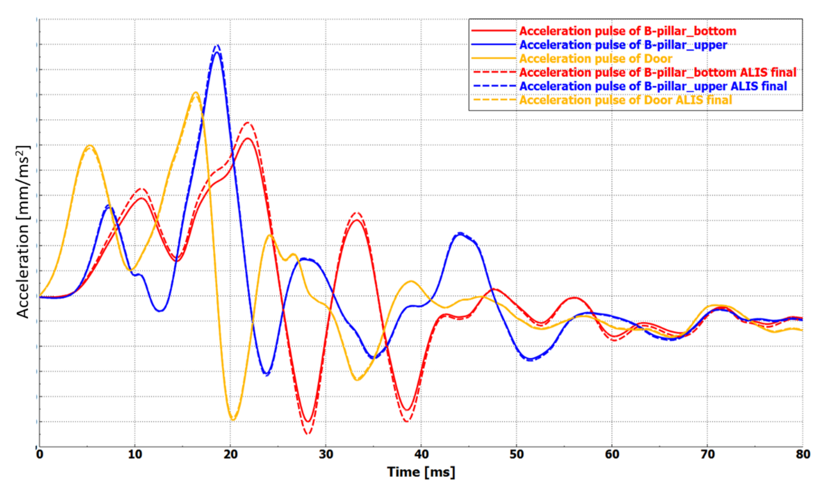
Results for praxis

Main advantages for the practice can be seen in less time demanding and so less expensive development and swifter testing. Also, less prototype parts for the testing are required. Should the approach be used in broader scale, it may get cars and other vehicle affordable to more people.









First thorax rib	Deviation at 48ms in [%]			
	Full crash simulation	ALIS simulation	ALIS test	Full crash test
Full crash simulation		8.0	34.9	35.6
ALIS simulation	7.4		24.9	25.5
ALIS test	25.9	19.9		0.5
Full crash test	26.2	20.3	0.5	

Name	Deviation of	Deviation at max value	Deviation of	Deviation at max value
First thorax rib	ALIS simulation vs full simulation	11.2%	ALIS test vs full crash test	3.2%
Second thorax rib	ALIS simulation vs full simulation	10.6%	ALIS test vs full crash test	7.4%
Third thorax rib	ALIS simulation vs full simulation	8.5%	ALIS test vs full crash test	37.4%
First abdomen rib	ALIS simulation vs full simulation	12.4%	ALIS test vs full crash test	7.5%
Second abdomen rib	ALIS simulation vs full simulation	1.4%	ALIS test vs full crash test	1.1%

There are three ranges of acceptance:

- Green - Deviation within 10% is considered as a very good match
- Yellow – deviation between 10%-20% is considered as a decent match
- Red – deviation above 20% is considered as not good correlation with the physical test

Literature

[1] Wilson, B., Cappelleri, D.J., Frecker, M.I. and Simpson, T.W. Efficient Pareto frontier exploration using surrogate approximations. Optimization and Engineering, 2 (1), pp.31-50, 2001

[2] Guo H., Mettas A. „Design of Experiments and Data analysis", 2010 Annual RELIABILITY and MAINTAINABILITY Symposium; https://www.weibull.com/pubs/2010_RAMS_doe_and_data_analysis.pdf

[3] Myers R. et al. „Response Surface Methodology: Process and product optimization using designed experiments 4th edition", Wiley, 2016; ISBN 978-1-118-91601-8

[4] Rutherford A. et al. „Use of response surface metamodels for identification of stiffness and damping coefficients in a simple dynamic system", Shock and Vibration 12 (2005) 317–331, ISSN 1070-9622/05

[5] Dean A., Voss D. „Design and Analysis of Experiments", Springer Verlag, 1999, ISBN 0-387-98561-1

[6] Cundy, A., et al. „Use of Response Surface Metamodels for Damage Identification of a Simple Nonlinear System", Key Engineering Materials. 245-246., 2003, 10.2172/812182, https://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-03-1182

[7] Cundy, A. „Use of Response Surface Metamodels in Damage Identification of Dynamic Structures", master thesis, 2003, Virginia Polytechnic Institute and State University, https://vtechworks.lib.vt.edu/handle/10919/30842

[8] Jiju, A. „Design of Experiments for Engineers and Scientists", Elsevier's Science and Technology, 2003, ISBN 0 7506 4709 4

[A01] Jelinek J., Růžička M., Kalinský M. „Advanced Methods in Crash Safety Testing", In: EAN 2018 56th conference on experimental stress analysis, Conference Proceedings. Praha: Czech Society for mechanics, 2018. p. 150-156. ISBN 978-80-270-4062-9

[A02] Jelinek J., Růžička M. „ New advanced methods in side crash testing", MECCA: Journal of Middle European Construction and Design of Cars 2021; DOI: 10.14311/mecdc.2020.02.01.

[A03] Jelinek J., Růžička M., Kafková A. „New methods in side sled crash testing", International Journal of Crashworthiness; 2021, ID: 1904651 DOI:10.1080/13588265.2021.1904651.