eta/VPG™: A Virtual Crash and Safety Environment for FMVSS and ECE Standards

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Summary

Vehicle manufacturers, in an effort to reduce costs and meet the demand of customers are constantly reducing product development time. At the same time we see more regulations from governments, primarily aimed at vehicle safety. In additions there are variations in global regulations, such as ECE and FMVSS regulations.

In order to meet the objective of reducing time and costs, manufacturers are forced to rely more and more on the virtual prototype to avoid the time and cost of constructing and testing prototypes, and to gain the insight necessary to make the current vehicle design better than past products in the area of performance and efficiency.

These, in the minds of the engineering community, may be contradicting objectives. We have less time to perform more analyses, and not only that, but more critical analyses which may have more impact on the success of the vehicle when compared to the commercial impact of the analyses performed 5-10 years ago.

The automotive industry is legally required to design vehicles to meet the Federal Motor Vehicle Safety Standards (FMVSS) or ECE/EEC Homologation Regulations as well as Corporate/Industry Standards. These standards are ever-increasing due to consumer awareness and the industry focus on vehicle safety, resulting in a conflict – we are increasing the simulation workload, and shrinking the time available to perform the analysis. Therefore, there exists a need to streamline all routine processes, and gain maximum efficiency from the engineer’s limited time.

This paper describes the development of a set of tools which enable engineers to automate many routine crash and safety analysis tasks, gaining efficiency, accuracy and productivity.

Keywords

Crashworthiness, Safety, Simulations, Customization, Regulations, FMVSS, ECE, EEC, LS-DYNA, eta/VPG and Virtual Proving Ground

1.0 Introduction

Vehicle manufacturers, in an effort to reduce costs and meet the demand of customers are constantly reducing product development time. At the same time we see more regulations from governments, primarily aimed at vehicle safety. In additions there are variations in global regulations, such as ECE and FMVSS regulations.

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These, in the minds of the engineering community, may be contradicting objectives. We have less time to perform more analyses, and not only that, but more critical analyses which may have more impact on the success of the vehicle when compared to the commercial impact of the analyses performed 5-10 years ago.

The solutions, which are sought to meet these conflicting objectives, really focus on the simulation tools, which engineers use to create the detailed crash analyses models from which vehicle design evolves. These tools have 3 key components, analysis solver, computing resource and the engineer.

Simulation tools used in vehicle crash simulations are based on explicit nonlinear dynamic finite element programs such as LS-DYNA. This program has allowed the engineer to simulate the behavior of complex crash situations such as dynamic side impacts. This capability has allowed for the reduction in the need for prototype testing, and has allowed for the detailed study of the energy absorbing mechanisms within the vehicle. The result is a vehicle design that has been tested less than previous generations of vehicles, but has a better performance in the area of crashworthiness.

Obviously, another key to providing this solution is the ever-increasing computing resource available to perform these simulations. Cost per mega flop values have steadily decreased, and are expected to continue to decrease. These advancements in have seen the average crash model size (elements) increase by 2-4X over the past 5 years, with the computing time reduced by at least 10X.

This leaves the engineer as the final area which improvements and efficiency needs to focus. The engineer creates the model, interprets the model and drives the vehicle development through a combination of analytical ability and creativity. Therefore, a new focus on freeing the engineer to be more analytical and creative needs to be formed. One way to provide this freedom is to reduce the routine tasks performed by simulation engineers, automating as many labor intensive tasks as possible.

When the simulation process itself is studied, it can be found that since the inception of vehicle crash analysis, the model creation is the most time consuming and critical step in the overall process. Proper modeling of the vehicle components, accurate connections and proper implementation of the contacts and material models used in a crash model all re critical in the success of the model.

Another area which impedes the development of these crash models is the ability of the engineer to understand a wide variety of simulation types. For instance an engineer in vehicle safety department may be required to understand, and interpret into a finite element model, dynamic side impact, roof crush, frontal and rear impact. While there are similarities between these types of events, there is a significant difference in the manner in which the models are constructed and analyzed. There exists a need for the engineer to have access to a variety of testing procedures and the impactors, barriers or occupant models needed for each of these simulations.

To address each of these needs and to provide the productivity enhancements to the engineer, a set of tools, called VPG/Safety, have been developed.

2.0 VPG Crash/ Safety Environment Requirements

Crashworthiness and Occupant Safety Account for approximately 60% of the simulations performed during a typical vehicle development. During program development phases different effort is required. In current time there various finite element packages that has strength to perform to today's engineering expectation. Their strength could be in preprocessing, auto mesh, model setup or post processing. These packages try to do each of these efforts as a part of their strength.

During concept phase a quick check to see if the vehicle meet the requirements is essential. A quick model setup will help the analysis to be performing very quickly. In this phase no detail modeling is required, but a correct simulation will let the engineer understand where the vehicle deficiencies exist.

During prototype and Production phase a detail model is necessary to simulate all requirement to meet FMVSS or ECE regulations. A good modeling package that should provide quick modeling scheme such as auto mesh, auto weld, penetration check and correction, easy model assembly is necessary. In all vehicle development phases a good post processing that can direct a user to see the necessary results is also required.

Crash/safety generally requires a structural assembly, (either a full vehicle or a component of the vehicle), and at least one crash tool model (dummy, barrier, rigid wall etc.). During the simulation either a structure moves at a particular speed into a crash tool, or a crash tool impacts the structure. The displacement of the structure, the acceleration (or de-acceleration) pulse, the G-forces on the dummy models, and certain specified results are then post-processed and compared with the performance criteria and legislated requirements.

These analyses are based on well-defined testing procedures that are documented in FMVSS or ECE regulations. The preparation of the test specimen and the test conditions, as well as the measurements to be performed are all specified in these documents. Therefore, we have an excellent blueprint from which to specify our analytical procedure. These testing procedures are quite fixed and lend themselves to be easily converted into a process, and in turn into an analysis procedure.

In each analysis the user first establishes a validated structural model including proper mesh, material properties, contact definition and correct connectivity to satisfy the given modeling guidelines.

The structure model is then placed in simulation position; most model positions are equivalent to the vehicle design coordinate system, however, some are defined in an alternative "testing fixture" coordinate system.

The crash tool model is then placed in a particular location and in a certain direction. In most cases, the crash tool model position is given. Occasionally, users will have to define the location and direction, if there is no default standard. In occupant safety cases, the dummy models are placed on the seat at the H-point or a test fixture position

The prescribed impact velocity and direction are given as default values according to legislated criteria, with the user being able to alter these values according to individual case test requirements.

The simulation results have to be output according to the case requirements, therefore, the nodes, contact surfaces and sections are defined either automatically or by user defined node set, segment set and section during the setup process. The output request and the frequency (sampling rate) are also defined for post-processing purposes.

Legislated criteria, such as HIC, TTI and Femur Load are calculated in addition to the crash pulse, impact force and contact force, and can then be post-processed.

In order to provide a consistent process for each type of test, the specific test process can be implemented via software tools. These tools must fit into the current CAE environment by supporting the various simulations which are used in vehicle development. In addition, it is critical that they interface with the existing crash analysis software, especially the analysis solvers.

A crash/safety environment for virtual test has been developed under eta/VPG software, providing procedures and processes that can be used to streamline and standardized the analytical process.

3.0 VPG Crash/ Safety Environment Benefits

VPG/Safety is an environment where the analysis procedure of doing Crashworthiness and Safety Simulations is coded in the software. The environment in VPG is user friendly and database compatible with LS-DYNA, supporting all data defined in the LS-DYNA user manual. Utilizing a step-by-step approach the user is able to write out the input file for the analysis with all data defined in VPG, without any text editing required.

VPG offers a solution to the Crash/Safety CAE enabling them to can achive the following:

Quality
- Commonized simulation methods
- Reduce human error

Productivity
- Cost Reduction

Processing
- Reduce model preparation time

3.1 Increased Quality by Automation

Increasing quality of a product is a driving factor in all areas of design, manufacturing and CAE technology. ISO 9000 has been introduced in all areas of design and manufacturing to enhance the quality of products through consistent processes which are carried out through the entire organization. This concept is also being driven down to the CAE engineer, requiring an identifiable, controlled process by which simulation models are created, and analyses carried out.

One of the way to provide this controlled process is to provide a software tool where the analysis process is integrated into the model construction process, thereby reducing the human error, and variation among engineers. The VPG/Safety envoironment offers this feture by seting up the environment for a particular simulation. A simulation will be setup based on ECE or FMVSS requirement. Default parameters are defined for each simulations, but engineers still have the ability to change any defult values as necessary, or as experience dictates. This type of automation will reduce human error and provide means to implement best practices throughout an organization.

3.2 Increased Productivity

Enhancing the productivity of engineers who create and analyze the simulation models for vehicle safety is the key to implementing virtual prototypes for vehicle development. This productivity increase, of course, must be made without any sacrifice in the quality of the simulation model or resulting analysis. By implementing the VPG/Safety module, the model set-up process may be automated, eliminating a potential point for the introduction of modeling errors. In addition, once the engineer is free from this task, there will be additional time available for the engineer to be an “engineer”, and identify solutions to crashworthiness and occupant safety problems – not struggle with data management issues.

3.3 Reduce Processing Time

The seamless tie between pre-processing, analysis and post-processing capability of LS-DYNA and VPG reduce processing time to setup LS-DYNA files. No text editing before and after analysis enables the user to save time and effort for a simulation.

4.0 VPG/Safety Software Tools

The VPG/Safety component is organized into three modules :

Crash Tool Library
- consists of all necessary crash tool models, dummy models and barrier models, impacters, etc.

Vehicle Crashworthiness Modules
- includes FMVSS, ECE/EEC and Industry Standards

Occupant Safety Modules
- including FMVSS, ECE/EEC and Industry Standards

4.1 VPG Crash Tool Library

The VPG/Safety module has all necessary Finite Element model crash tools that are used for FMVSS, ECE/EEC and Automotive industry standards. This module contains a default set of tools that has been developed by joint venture of ETA and Wayne State University, Bio-Mechanical Engineering Department and LSTC.

The dummies included in the library are mixed rigid/flexible bodies and rigid joints. Barrier Models have been constructed according to the FMVSS or ECE specifications, and are modeled in an efficient, yet accurate manner. The Crash Tool Library consists of:

Dummies:
- SID and EUROSID Dummy Models
- Hybrid III Dummy Models
- Child Dummies (capability to handle FTSS child dummies)

Barriers:
- FMVSS/ECE Side Impact Barrier
- 0-Degree Front Rigid Barrier
- 30deg Rigid Front Barrier
- Front Offset Deformable Barrier
- Rear Impact Barrier

Impacters:
- Rams
- Pendulums
- Head Forms

These tools have been developed and correlated over a series of actual vehicle programs. This tuning and improvement of models has been made using a wide variety of vehicles, from mini-cars to transit vans, providing a set of robust tools which can be used with confidence.

Alternately, VPG/Safety allows users to incorporate their own set of crash tools, and save them in the library for future use. This provides a way for the existing best practice to be incorporated into the set of tools used for all vehicle crashworthiness and occupant safety analyses.

4.2 Vehicle Crashworthiness Modules

Vehicle crashworthiness is comprised of typical crash test which are carried out on full vehicle systems. In order to perform analyses which are compatible with vehicle testing, it is required that the engineer have a thorough understanding of the appropriate governmental regulation. In order to facilitate this requirement, the VPG/Safety modelule currently support a wide range of vehicle crash scenarios in both the FMVSS and ECE environments.

When a user selects the Crashworthiness Module, they are placed in an anvironment where the appropriate loading mechanism (barriers, impactors, etc.) and occupant models (Hybrid III, SID, EUROSID) are brought into the model. The user is then prompted for the data necessary to position these tools, according to the test procedure. Boundary conditions and contacts are automatically defined, again using the appropriate test conditions. By using this environment for any of these analysis cases, it allows the engineer to work quicker and with added confidence that the modeling has been performed correctly (See Figure 1 and Figure 2)

Documentation is provided along with the software, containing the necessary information about the FMVSS/ECE/Industry standard test procedure, and also with step-by-step approach in setting up an analysis input file. It also guides the user to check the necessary results files for different regulations.

Post-processing of all ASCII and binary database files created from the LS-DYNA analysis can be performed using VPG/Safety, which has the ability to read these files directly.

The VPG/Safety software contains the analysis scenarios which are commonly performed as part of full vehicle development programs.

FMVSS Regulations

FMVSS 214b (Side Door Intrusion)
FMVSS 214 (US Dynamic Side Impact)
FMVSS 208 (Rigid Wall 0 Degree/30 Degree)
FMVSS 216 (Roof Crush Resistance)
FMVSS 301 (Flat Rigid Wall Rear Impact)
FMVSS 301 70% Overlap Deformable Barrier Rear Impact

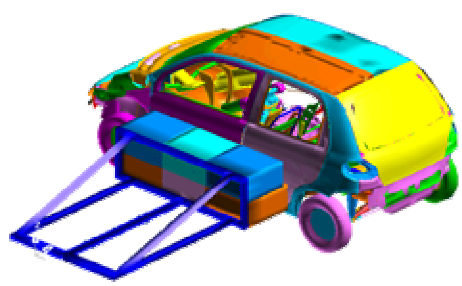


Fig 1. ECE95 Side Impact

ECE Regulations

ECE 94 (Deformable 40% Offset)
ECE 12 (ECE 33, ECE 34) ADR 69
ECE 33/34 (Rear Impact)
ECE 95 (Euro Dynamic Side Impact)

Insurance/Consumer Requirements

Front Rigid Pole Impact
Side Pole Impact
IIHS 40% Offset Deformable barrier Front Crash
AMS (Rigid 15deg, ASD 50% overlap Anti-sliding device)
Bumper Impact Analysis (Flat, Offset, Pendulum)

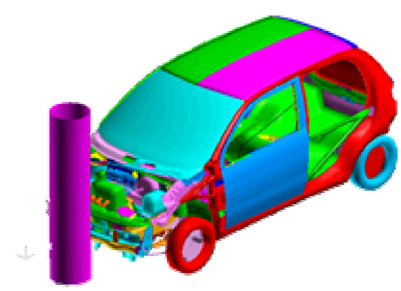


Fig. 2 Front Rigid Pole

An example of how these tools may be used to construct a ECE 95 side impact analysis is shown in Figure 4.

4.3 Occupant Safety Module

As with the full vehicle crashworthiness analyses, Occupant Safety analyses follow governmental regulations with respect to the set-up and performance of specific tests. These tests are typically aimed at vehicle subsystem performance, and focus on interior system components such as seats and instrument panels.

VPG/Safety creates an environment where the appropriate tools are imported and efficiently positioned in the model, applying the correct boundary conditions and automatically creating contact interfaces when appropriate (See Figure 3).

As with the Crashworthiness Module, documentation is provided, which contains the necessary information about the FMVSS/ECE/Industry standard test procedure, and also with step-by-step approach in setting up an analysis input file. It also guides the user to check the necessary results files for different regulations.

The VPG/Safety software contains the Occupant Safety analysis scenarios which are commonly performed as part of full vehicle development programs.

<u>FMVSS & ECE Regulations</u>

FMVSS 201 (Free Motion Head Impact, Study)
FMVSS 207/210 (Seatbelt Anchorage Study)
FMVSS 225 (Child Restraints anchorage system)
FMVSS 208 (Sled Test Occupant Simulation)
FMVSS 208 (Knee Bolster Simulation)
FMVSS 203 (Steering Control System)
ECE 17 (Luggage Intrusion)

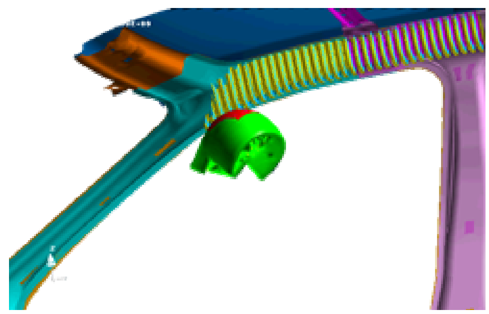
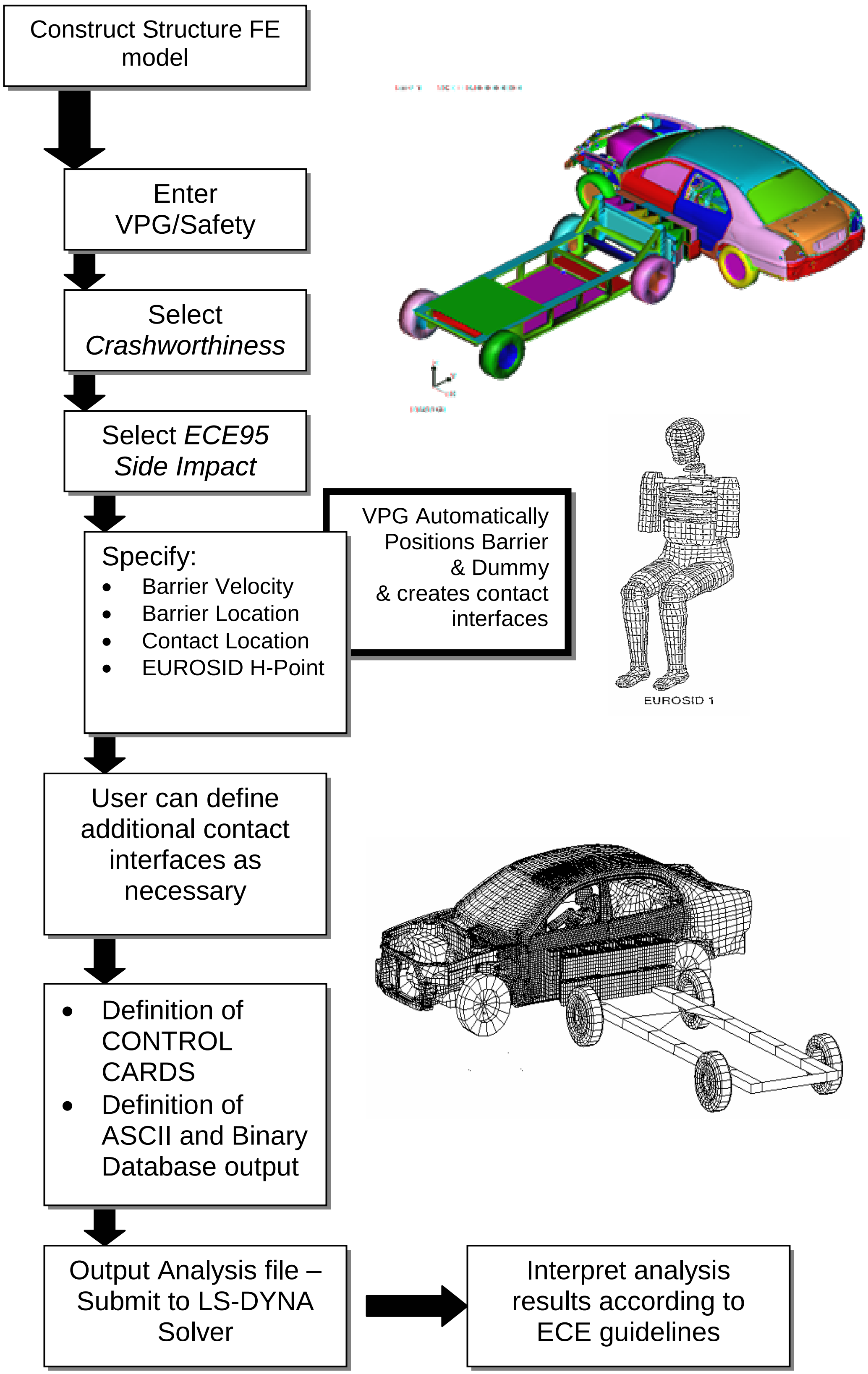


Fig. 3 Free Motion Head Impact

The use of these tools allows for the user to accurately and efficiently position the tools according to the test procedure, and automatically define the boundary conditions and contacts required for the analysis.

Fig 4. VPG/Safety Modeling Process Flow



Conclusions

The development of software tools for the automation of model creation and analysis set-up have the potential to have an impact on the productivity and quality of crash simulations. These types of tools will be required to meet the ever-increasing demands on the CAE engineer, allowing them to meet the timing and technical requirements placed on them. VPG/Safety is such a software tool, enabling engineers to quickly create finite element models of vehicle structures, position the vehicle and crash tool in a manner appropriate for the test under consideration, and execute the analysis with minimal manual intervention.

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