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Optimum gas tank locating in van vehicle – front and side crash analysis consideration for passenger safety

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A B S T R A C T

In this research, crash test results from CNG locating method optimization approach for crashworthiness and testing its safety are presented. The locating process is based on principal energy considerations inspired from the current design process in passenger vehicle design development. The potential of the vehicle concept to absorb kinetic energy can be estimated at the very beginning of the design process by the free crash lengths in the different areas of the vehicle and estimates of average forces required in the specific segment and parts of the car body at particular crash phases. Based on the basic principle of vehicle crash analysis using the finite element method, a passenger VAN finite element model was selected to simulate the front and side rear collision test of the VAN, therefore the LS-DYNA software is adopted to calculate the deformation of the car and the acceleration time history curves during the crashing process; the anti-impact capability of the vehicle is evaluated from this simulation. It is important to determine appropriate force distributions and the corresponding loads paths through the whole structure for all relevant crash load in dedicated crash test cases. The results demonstrate that the improvement of local structure and location for the required CNG tanks in safe locations in vehicle chassis can promote the crashworthiness of the car, but the further improvement needs a major change of the vehicle structure. The outcomes are interpreted by using LS-PREPOST to analyze the energy absorption characteristics during crash for different cases at a velocity of 50km/h the duration of 12ms. The result analysis was necessary to derive distinct deformation phases characteristic and following that, the essential crash elements are compared with and without CNG tanks installation in each crash case. At last, the conclusion determines the proposed tank locating model in the selected passenger VAN is within the safe range of crash analysis standards.

1. Introduction

Global concern for the environment has been increasing throughout the last 2 decades, and green technologies are being emphasized all over the world. Carbon dioxide (CO_2) emissions from the transport sector increased from 3950×109 kg to 5370×109 kg (3950 – 5370 Mt) between 1990 and 2005, representing 20% of total fossil fuel CO_2 emissions (Ye et al., 2020). Many companies are introducing efficient manufacturing processes, recycling efforts and environmentally friendly products. With the vehicle industry cited as a major source of pollution, vehicle manufacturers are putting a lot of efforts to produce cleaner cars and trucks. Besides, the world is facing the ever-increasing challenge of energy

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shortage that is mainly resulted from an over-dependence on fossil fuel energy sources. The transport sector worldwide almost entirely relies on fossil fuels, oil in particular. Its oil demand increased from 1020x106 tons of oil equivalent (1020 Mtoe) in 1973 to 2162 Mtoe in 2007, with its share in the total oil demand rising from 45% in 1973 to 61% in 2007 (Annan et al., 2015). In this manner, demands for other alternative fuels (instead of fossil fuels) are increasing every year. Governments are trying to produce cars that are working with other fuel types like Natural Gas, Electricity or mixed fuels vehicles. The development of alternative fuels, such as natural gas, for automotive has become very essential because of the continuous decrease in the petroleum reserves and also their contribution for pollutants. Compressed Natural Gas (CNG) is now emerging as an alternative energy source for the automobile sector and gaining much interest in research work. Although using CNG is very useful due to aforementioned advantages, yet there are a lot of concerns about safety. These include safety of the onboard CNG tank and equipment installation, safety of refueling facilities and installation and safety of the CNG tanks in case a car accident occurs. It should be mentioned that, using safe CNG tanks and determining the appropriate location to install the CNG tanks in the vehicle chassis body has become a very important topic in scientific studies in the last decade and this interest has caused variable tank configuration and location optimization to be tested for producing safer gas storage tanks but at the same time improving its weight and efficiency (Nijboer, 2010). The material of the gas tank, the location of the gas tank, the refueling method and components used are important factors that can increase both safety and performance of CNG based vehicles. The most probable causes of failure for CNG vehicles are fire and vessel fracture since the maximum pressure capacity can be up to 200.0 bar (Kumar et al., 2017). Furthermore, in the vehicle body design, the safety of vehicle, structural integrity, crashworthiness, the injection process, combustion and flammability and, significantly, the location of the gas tanks are other important factors to be taken into consideration. The vehicle platform was developed to adapt CNG tanks with the main considerations of safety, tank shape, number and weight, mileage and refueling time. An important design criterion was not to reduce structural safety in platform during crash and these were simulated using various designs of structural reinforcements and tank mountings. Many works have been done on improving and optimizing a passenger vehicle body with minor modifications to the chassis and inner components to make enough space for the gas cylinders. This type of vehicle normally carries up to 5 adult passengers. However, to the best of the author's knowledge, very little work on the identification and the location optimization of CNG tanks in VAN-like type of vehicles have been done (Makarova et al., 2019). In Malaysia, VANS are used to carry school children, workers and small groups of tourists. The VAN has a capacity of up to 18 passengers. The present work focus is on the Ford CNG VAN and its finite element model is based on Ford Econoline. The following FE model in this research is developed by the George Washington University National Crash Analysis Center and also used in the support of several NHTSA (National Highway Traffic Safety Administration) programs. Ford Econoline is a very popular and effective VAN that plays a key role in public transportation globally and in ASIA PACIFIC including Malaysia. Another very similar VAN which is currently used for transportation in Malaysia is the Toyota HiAce. Many of these motor vehicles are equipped with CNG gas tanks (Khan et al., 2016). In this study the main focus is on determining the best location of the gas cylinders on the vehicle to meet safety, minimum weight and optimized sizes along with achieving higher mileage of driving distance.

This aim of the present study is to enhance the location and performance of the passenger Vans that are running on CNG with the maximum impact and increase its capacity without compromising the safety and crashworthiness. The research objectives are defined as follow:

I. To determine a safe location for gas containers in passenger VAN in order to improve the safety and increase the performance of the vehicle.
II. To develop a generalized model for an appropriate framework design and locating the gas containers for different vehicle body type and shape.
III. To determine the crashworthiness characteristics of the VAN frame in Euro-NCAP impact safety crash test.

IV. To predict safe seat anthropometry space models for crashworthiness safety of CNG VAN passengers.

The outcomes of this study will help research institutions and car manufacturing companies to determine a safe and optimized location in the platform for VAN type of vehicle, particularly the shape and location of the gas containers to increase passenger safety and crashworthiness performance of the VAN.

2. Scope and limitation of the research

The scope of this study is GAS based motor vehicles specifically Ford Econoline Vans.
The selected VAN is a passenger type vehicle with the capacity of 10 to 14 passengers.
The detailed scope and limitation of the study based on the date of the study (2012-2018) are as follows:

I. It is considered that the safety of VAN can be increased by optimizing the location of the gas cylinder.
II. This study only investigates the gas cylinders that are prepared to use CNG and no other types of gas.
III. The project will be carried out in Malaysia, however the results can be expanded to use in other countries.
IV. To verify findings, the approaches and methods in virtual systems must be examined using simulation. Then in the next step, the proposed approaches shall be validated in real Vans to verify the results.

3. Significance of the Study

As seen so far, the oil reserves in the world are depleting and cause pollution. On the other hand, natural gas is plentiful and has cleaner emissions. CNG as an environment friendly fuel which causes less emissions compared to fossil fuels is now very favorable. Using CNG is dangerous since it is flammable, high pressure and also it can cause massive explosions. Therefore, NGV systems must be designed to ensure a high safety level of the motor vehicle. Safety is the main factor to be considered for vehicles like VAN. Generally VANs in Malaysia can be used with multi transportation purposes like transporting school students, or for instance using in Hotel as shuttles for transportation or taking passengers (tourisms) for taking tours in Malaysia (Odeta, 2013). Vehicles Importance of this study can be summarized in points below:

I. Increasing the safety of the Vans by improving the location of the gas cylinder.
II. Determining a save predictive seat anthropometry space for passengers by optimizing the location of the gas cylinder in Vans.
III. To find the optimum design and number of gas cylinders which maximizes the performance of the Vans.

There are more than a million NGVs in India and 450,000 in China. Pakistan boasts 2.7 million NGVs, and then we have Iran, Argentina and Brazil each with more than 1.5 million apiece. International Association for Natural Gas Vehicles (IANGV) believes the global NGV fleet will increase at least 10-fold by 2020 – topping 50 million. With the current rate of consumption, global proven Natural Gas reserves would be depleted in 42 years as shown in Fig. 1. We can see an after accident photo that has happened due to crashing a CNG vehicle to another vehicle, and the explosion power is extreme and can end up to complete loss of passengers and vehicle. A typical CNG vehicle would normally include the assemblies (Fig. 2). CNG source would be CNG cylinder which requires securely be located into the car body and the rest of the components are installed into the vehicle body in different proper locations according to the standards of the CNG manufacture. Fig. 2 shows how a typical locating of CNG cylinders would be in a Ford vehicle. In this model there are three cylinders used and two are located instead of where the sparse tire is normally in cars and the longer cylinder is located into the chassis frame along with the length of the vehicle. As we also can see in Fig. 3, there is another format of locating four cylinders into the chassis on the same Ford vehicle. Within the chassis frame would be still the safest area in locating another cylinder to help to increase the capacity of gas storage which can end up using the vehicle for driving in longer distance.

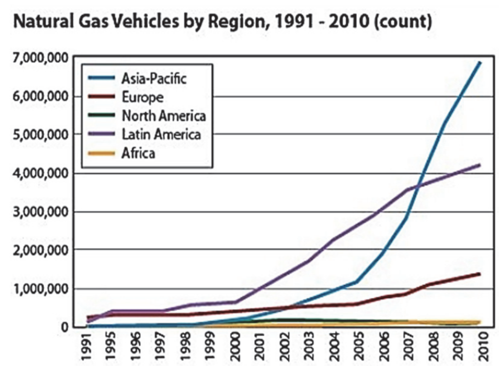

Fig. 1. Natural gas growth worldwide 1991-2010, (Right Image)

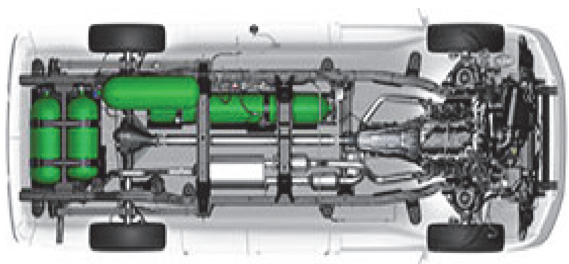

Fig. 2. A CNG based car with Four Gas Capsules
(Retrieved 17 September 2019 from http://www.boronextrication.com/2013/02/27/2012-gm-express-savana-cng-lpg-tank/)

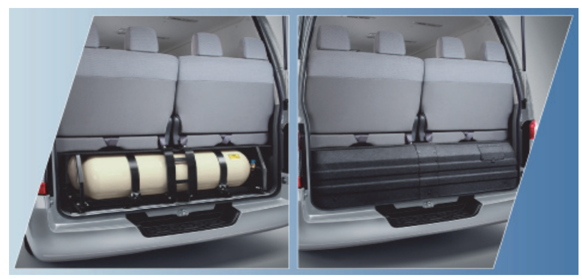

Fig. 3. Vehicle with two 100-liter CNG tanks
(Retrieved 15 August 2019 from https://gazeo.com/automotive/vehicles/Nissan-NV350-Urvan-CNG-debut-in-Thailand,article,7700.html)

Another location is shown in Fig. 3 in below for a Nissan VAN using two cylinders in the rare section of the vehicle. Fig. 3 shows a typical SUV vehicle with locating four gas cylinders. Two cylinders located in the rear section and another two cylinders along the length of chassis. As you can see all are inside the chassis frame for higher protection. Table 1 shows detailed materials of gas tank types and safety factors required.

Table 1. CNG tank types by designation and critical construction materials, Wozniak et al., (2001)

CNG Tank Type	Liner Materials Typically Used	Composite Materials Construction Often Considered
Type I	Metal Linear (Steel)	No composites; Steel only
Type II	♦ Metal Limer (Steel or Aluminum) ♦ Hoop fiber wrap only	♦ Fiber options are glass-fiber or carbon-fiber typically
Type III	♦ Metal Liner (Aluminum) ♦ Both hoop and helical complete fiber overwrapping of liner	♦ Fiber options are glass-fiber or carbon-fiber typically ♦ Aramid-fiber also an option ♦ Hybrid fiber mix also has been used (glass-fiber and carbon-fiber)
Type IV	♦ Plastic Liner (HDPE typically) ♦ Both hoop and helical complete fiber overwrapping of liner	♦ Fiber options are glass-fiber or carbon-fiber typically ♦ Aramid-fiber also an option ♦ Hybrid fiber mix also has been used (gladd-fiber and carbon-fiber)

4. Literature review

This section presents a review of researches that have been carried out in designing; locating and forming gas tanks in CNG based motor vehicles. In-depth analysis has been carried out by reviewing 70 dominant research papers available in the literature. Major shortcomings in designing and locating gas tanks are illustrated and advantages, limitations and drawbacks of each of the opted researches are explained. The domain of studied methods includes composites of gas tank, shape- designing, injecting system and locating gas tank as the main objectives of this research. Since some of the studied models are complex, in each section of this section, a deep research on advanced complex methods such as heuristics are also investigated along with the exact solving methods. Outcomes of this work could determine gaps in the knowledge base and provide directives for objectives of this research as well as future research which will help in clarifying many related questions in the mentioned problem statement.

4.1 The European New Car Assessment Programme (Euro NCAP)

Consumer information crash test programs have proved effective in improving car safety in a number of countries. The European New Car Assessment Program (Euro NCAP) was developed in the United Kingdom with the aim of bringing about such improvements throughout the European Union. Euro NCAP has grown with sponsorship from other European countries, the European Commission, European consumer groups and international motoring organizations (Happian-Smith, 2001). Most manufacturers have become more positive about Euro NCAP and the industry is now contributing to the development of the program. More importantly, many manufacturers are responding rapidly by improving their cars and by standardizing safety features throughout the European Union. The rate of improvement in occupant protection is such that reductions in car occupant casualties should soon be identifiable in accident statistics.

4.2 Euro NCAP Test Procedures

Assesses the protection for car occupants, in frontal impact and side impact. The test procedures used are based on those developed by the European Enhanced Vehicle-safety Committee (EEVC), for legislation in Europe. Euro NCAP was established to bring the benefits of consumer crash testing to the whole of Europe. Despite objections, the industry has responded by making rapid improvements to the cars they produce. Although some manufacturers are still negative about the program, many others are positive. They have identified the marketing advantages which can be obtained by performing well and they appear determined to take advantage of them. There are still improvements which are necessary and difficult decisions have to be taken about how they can be incorporated. It can already be seen that the Euro NCAP tests have been accepted by most as the tests which are setting the standard for future crash protection. This places a great responsibility upon Euro NCAP to ensure that its requirements are both well founded and effective (Szczęśniak et al., 2014).

4.3 Analysis of VAN Body Structure

The design of chassis and frames of the VAN body is the most important stage of vehicle production. There is some historical information for showing development in vehicle production. Many of VANs properties are strictly connected with the chassis or frame. Dynamic properties and static or geometric parameters of the vehicle depend on chassis or frames (Burdzik et al., 2014). Automotive industry is one of the biggest and most innovative in the total industry area. Almost all manufactured cars and vehicles are made by mass production but in the very beginning the cars were produced by the same technologies of hand craftsmanship that had been used for centuries for the construction of horse-drawn carriages. Due to the issue of large numbers of components and assembly relying on joining items the procedure has been changed (Burdzik et al., 2012). It was started by Henry Ford who developed the techniques of mass production based on preliminary production of rifles during American Civil War. The line production was based on special tracks, so the car's chassis were moved through next assembly stations with overhead store components. Thus the motor industry from small workshops producing hand-build vehicles changed into a huge corporation with mass production techniques with components supply chain. Second main factor of changing the production processes and techniques was construction development. From the first construction based on horse-drawn carriages with wooden chassis and framework to the modern constructions of steel, lightweight steel (or even ULSAB – Ultra Lightweight Steel Auto Body) or fiber constructions (Blacha et al., 2013). In addition to the direct engineering issues the vehicle designer needs to consider the political issues such as pollution and recycling. Thus the research on materials of the engine and vehicle body in terms of environmental and safety are constantly conducted. The novel materials cause changes in construction due to the different physical and mechanical properties (Folęga, 2013). The requirements for modern cars and heavy vehicles cause many tasks in vehicle design. Beside the fundamental tasks such as proper identification of engine, transmission system, steering, suspension, brakes in terms of safety, utility and comfort the material properties and structure geometry become more and more important. Also the noise, vibration and harshness become important requirements for the customer. It has to emphasize the role of endurance and durability in the design and manufacture of reliable vehicles. The requirements for utility vehicles have increased as well. The range and scope of potential use and application possibilities become very wide. Thus these vehicles start to be considered for the customer not only in terms of utility but more often in terms of comfort and safety as it is in passenger cars. These are the reasons for innovation solutions in modern vehicles. One of those is an intermediate frame. The requirements for the intermediate frame are focused on loads (goods) or vehicle use and stability of body (superstructure). As far as vehicle application or load requirements determine shape and volume of the construction, the stability will be realized as stiffness and spring/damping properties of the connections. Torsionally stiff bodies may not affect the torsional flexibility of the chassis frame. They must be connected to the chassis so that they are torsionally flexible in accordance with the specifications of the body/equipment mounting directives. Fixed bearings and pivot bearings are used for this purpose. Due to types of special bodies the mounting of implements and bodies become very important (Szczęśniak et al., 2014). The process of chassis design consists of: - load case, - chassis type, - structural analysis. Very important issue of vehicle design is selection of material according to experimental and analytical data and maintenance properties (i.e. corrosion resistance).

4.5 Vehicle Chassis Analysis

Vehicle chassis and frame design is one of the fundamental and most important stages during the designing is proper development of chassis and frame of the vehicle, especially for special heavy vehicles. Design of the vehicle chassis has to be started from analysis of load cases. There are five basic load cases to consider:

I. Bending case: loading in vertical plane, the plane due to the weight of components distributed along the vehicle frame which cause bending about the axis;
II. Torsion case: vehicle body is subjected to a moment applied at the axle centerlines by applying upward and downward loads at each axle. These loads result in twisting action or torsion moment about the longitudinal axis;
III. Combined bending and torsion loads
IV. Lateral loading: generated at the tire to ground contact patch. These loads are balanced by centrifugal forces;
V. Fore and aft loading: generated when vehicle accelerates and decelerates inertia forces (Reimpell et al., 2001).

An example of the worst-case loading conditions as well as overloading must be considered for the static load case. The factors usually applied to the static load case, especially for those vehicles with a long overhang containing concentrated loads (e.g., rear engine buses). Such loads result in high bending moments over the rear axle. The various dynamic conditions considered here for the determination of the axle loads are considered in (Douailler et al., 2011). If we consider the dynamic loads caused by vehicle-pavement interaction are either moving loads or random loads (Sert and Boyraz, 2017). There are some publications reporting a number of field measurements and theoretical investigations, which have shown that vehicle vibration-induced pavement loads are moving stochastic loads (Rys et al., 2016).

4.6 Vehicle Material Analysis

Nowadays a wide range of alloys is available with different properties, heat treatments and manufacturing opportunities. Thus these materials have now replaced steel and copper alloys in many vehicle components. New materials as aluminum alloys, polymers and composite materials are more often used even as vehicle bodywork (body panel). Thus the first stage will determine which group of metals or other materials can be used according to experimental and analytical data. Depending on the application the design engineer has to consider the material and mechanical properties due to the forces expected during the operation of the vehicle. A sufficiently strong force will produce a definite amount of deformation. Thus the designers and engineers have to understand and compare many parameters of the materials. For example: Strength, which is the ability of material to withstand a force without permanent deformation; Compressive strength, which is the ability to withstand a pushing force; and, Torsional strength, which is the ability to withstand twisting force. Other important properties are: tensile strength, elasticity, plasticity, hardness, toughness, dimensional stability and durability.

4.7 Simple Structural Surfaces (SSS)

Simple Structural Surfaces (SSS) method is offered as a means of organizing the process for rationalizing the basic vehicle body structure load paths. The application of this simplified approach is highly beneficial in the development of modern passenger car structure design. In Malaysia, the SSS topic has been widely adopted and seems compulsory in various automotive programs related to automotive vehicle structures in many higher education institutions. However, there is no real physical model of SSS available to gain considerable insight and understanding into the function of each major subassembly in the whole vehicle structure. Based on this motivation, a real physical SSS of sedan model and the corresponding model vehicle tests of bending is proposed in this work. The proposed approach is relatively easy to understand as compared to Finite Element Method (FEM). The results prove that the proposed vehicle model test is useful to physically demonstrate the importance of providing a continuous load path using the necessary structural components within the vehicle structures. It is clearly observed that the global bending stiffness reduces significantly when more panels are removed from the complete SSS model. The analysis shows the front parcel shelf is an important subassembly to sustain bending load.

4.8 VAN Chassis Design by using SSS

One of the most interesting methods for chassis and frame design for VAN is the SSS (Simple Structural Surfaces) method. It is a simple analytical approach for initial analyses of a preliminary design concept. The SSS method is used to analyze simple structures using thin plates as structural members. It can be considered as rigid only in its own plane. The representations of the vehicle structure by SSS have been described years ago in. There are two key assumptions made when analyzing a structure. The first is that the structure is statically determinate (Nor et al., 2017). This assumption limits the accuracy, especially in vehicle design where a number of redundant structures are used. The second assumption is that a sheet is unable to react out of plane loads, it has zero stiffness to loads applied perpendicular to the surface. When analyzing a vehicle a systematic approach is used where sheets are analyzed one at a time starting with sheets containing the input loads, which were calculated separately. The end result will be the edge loads of each sheet, as labeled in the Fig. 4 (Brown et al., 2001).

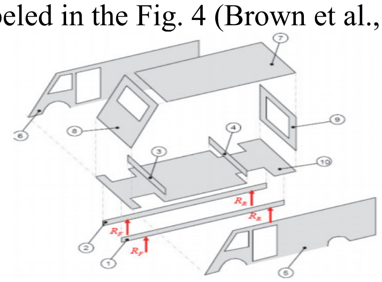

Fig. 4. SSS Van structure, where SSS 1-6: carry bending load, SSS 5-10: carry torsion load

An interesting solution to extend possibilities of regular frames or chassis for specific or defined purpose and utility is intermediate frames.

4.9 Disadvantages of the SSS method

Some disadvantages of the SSS method in vehicle design are:

I. problem in the design concept,

II. flexibility in the rear door frame of a simple box results in the torsion moment being carried entirely in the floor or chassis frame,
III. If the surrounding frame has low stiffness the glass may be loaded excessive.

For the commercial and special vehicles the utility of the vehicle during operation is very important. It becomes an impact factor especially for special heavy vehicles, which are dedicated for specific operating conditions and defined purpose of utility. Thus there are many types of chassis. Starting from historical ladder frames used by early motor cars. These frames have carried all load but they can accommodate a large variety of body shapes. It has good bending strength and stiffness but very low torsional stiffness. These frames are still used in light commercial vehicles like pick up and VAN. Other types are cruciform frames which can carry torsional loads because no element of the frame is subjected to torsional moment. It is made of two straight beams and has only bending loads. Torque tube back bone (tube-frame) frame is made of a closed box section as the main back bone. Traverse beams resist lateral loads and back bone frame bending and torsion. The advantage of using tubes rather than the previous open channel sections is that they resist torsional forces better. Typical chassis for a race car is a spaceframe, which is a lightweight rigid structure constructed from interlocking struts in a geometric pattern. Beam elements carry either tension or compressive loads by the inherent rigidity of the triangular frame. In both a space frame and a tube-frame chassis, the suspension, engine, and body panels are attached to a skeletal frame of tubes, and the body panels have little or no structural function.

4.10 Crashworthiness Analysis and Characteristics

The National Highway Traffic Safety Administration's vehicle aggressive and compatibility research program explores the global evaluation of vehicle crashworthiness designs as a means of minimizing injuries in the design vehicle while simultaneously minimizing injuries in the vehicle's collision partners. The project pursues both an analytic investigation of fleet wide vehicle performance as the basis for global optimization and pursues an experimental component as the foundation for validation of computer models and tools. The crashworthiness performance of passenger VANs traditionally has been evaluated on the results of well-defined laboratory crash tests. These tests, by their nature, focus on evaluating and minimizing injuries to the occupants in the subject vehicle. However, pursuing an optimal crashworthiness performance without regard to the crashworthiness performance of the collision partners can lead to very aggressive, incompatible vehicle designs. In the United States, there are several important research initiatives which are considering compatibility specifically and the overall fleet wide crashworthiness of vehicles more generally. First, within the last three years, the NHTSA Motor Vehicle Safety Research Advisory Committee's Crashworthiness Subcommittee established a special working group on Vehicle Aggressively and Fleet Compatibility. This working group was established as a result of the concern about the structural modifications being made by vehicle manufacturers in response to frontal offset crash testing being conducted throughout the world. These modifications included strengthening the vehicle structure in order to reduce the level of intrusion observed in the offset crashing. The stiffened structures have the potential of increasing the severity of side impact crashes. Also, there has been a recent concern over the increasing use of light trucks and vans (LTVs) as personal use vehicles. In the United States, LTVs have accounted for over one-third of new vehicle purchases. This group of vehicles generally is heavier and has stiffer structures than the passenger cars. The working group is developing a system model for evaluating vehicle crashworthiness on a fleet wide basis with the goal of identifying desirable vehicle characteristics for the various vehicle types and weight classes that will lead to improved fleet performance in the fleet crash environment (Khatri et al., 2018).

4.11 Global safety systems optimization model

In this study, a simulated VAN model is being developed to evaluate vehicle crashworthiness based on the safety performance of the vehicle when exposed to the accident environment. Optimal crash countermeasure designs must successfully balance two potentially conflicting objectives: (1) maximizing passenger protection in the vehicle under design, and (2) optimizing compatibility with other vehicles in the fleet mix. To meet these objectives, vehicle crashworthiness should be evaluated, not just on the basis of a few test configurations or test speeds, but also on the safety performance of the vehicle when exposed to the entire traffic accident environment. Note that, as in the real-world accident environment, this will expose the design vehicle both to vehicles less compatible and vehicles more compatible with the design vehicle. The means of evaluating vehicle crash performance on a system-wide basis was first accomplished by the Safety Systems Optimization Model developed by Ford Motor Company and later enhanced by the University of Virginia (Liao et al., 2008).

4.12 Injury criteria

The National Highway Traffic Safety Administration's (NHTSA) plans for upgrading the Federal Motor Vehicle Safety Standard (FMVSS) No. 208 frontal crash protection safety standard include improving protection requirements for the normally seated mid-sized adult male, as well as including additional requirements that will specify performance limits to minimize the risks from airbags to small sized occupants and children in both normal and out-of-position seating locations. These new crash specifications will require the use of additional dummies of various sizes as well as additional performance criteria that appropriately represent injury thresholds of these additional population segments.

Injury criteria have been developed in terms that address the mechanical responses of crash test dummies in terms of risk to life or injury to a living human. They are based on an engineering principle that states that the internal responses of a mechanical structure, no matter how big or small, or from what material it is composed, are uniquely governed by the structure's geometric and material properties and the forces and motions applied to its surface. The criteria have been derived from experimental efforts using human surrogates where both measurable engineering parameters and injury consequences are observed and the most meaningful relationships between forces/motions and resulting injuries are determined using statistical techniques. Development of human injury tolerance levels is difficult because of physical differences between humans. It is further complicated by the need to obtain injury tolerance information through indirect methods such as testing with human volunteers below the injury level, cadaver testing, animal testing, computer simulation, crash reconstructions, and utilization of crash test dummies. Each of these indirect methods has limitations, but each provides valuable information regarding human tolerance levels. Due to the prohibitive number (and cost) of tests required to obtain a statistically significant sample size using design of experiemnts (Delgoshaei et al., 2016), it ultimately becomes necessary to consolidate the available information each of these methods provides, and apply a judgement as to what best represents a reasonable tolerance level for a given risk of injury.

Crash reconstructions provide injury data under normal human physiological conditions, however, the forces and accelerations associated with those injuries must be estimated. Computer simulation and testing with crash test dummies provide valuable information, but these methods are dependent upon response information obtained through the other methods.

4.13 Head injury criteria

Existing NHTSA regulations specify a Head Injury Criteria (HIC) for the 50th percentile male. The biomechanical basis for HIC for the 50th percentile adult male was reviewed and alternatives to this function were sought. While considerable progress has been made in the capabilities of analytical finite element head/brain models to simulate the major injury mechanisms prevalent in brain injury, it was felt that it would be premature for their results to be used in this current proposed rulemaking action.

4.14 Neck injury criteria

Existing NHTSA regulations specify neck injury criteria for the 50th percentile male as part of the FMVSS No. 208 alternative test, S13.2. The previous biomechanics technical research describes in detail the derivation of the neck injury criteria, Nij, from biomechanical data (NHTSA Docket 1998-4405- 9). Comments received from various advocate groups suggested adopting conservative performance limits for the children in light of the real world injuries and deaths of children due to passenger air bags. Comments from the manufacturers in general supported the independent evaluation of neck forces and moments, rather than the evaluation of combined loads used by Nij. Three commenters (two manufacturers and one restraint manufacturer) supported Nij with a critical value of 1.4 based on practicability arguments.

$$N_{ij} = \frac{F_Z}{F_{int}} + \frac{M_Y}{M_{int}} \tag{1}$$

The resulting neck injury criteria, called "Nij", propose critical limits for all four possible modes of neck loading; tension or compression combined with either flexion (forward) or extension (rearward) bending moment. The Nij is defined as the sum of the normalized loads and moments, i.e., where FZ is the axial load, Fint is the critical intercept value of load used for normalization, MY is the flexion/extension bending moment, and Mint is the critical intercept value for moment used for normalization (Hasija et al., 2017).

4.15 Thoracic injury criteria

NHTSA currently mandates regulatory limits of 60g for chest acceleration and 76 mm (3 inches) for chest deflection. Considerable biomechanical information developed since the 1950's was used to assess potential loading thresholds for chest injuries and this information has been the basis for the existing criteria. Based on these statistical measures, the analysis demonstrated that while single variables, such as peak chest acceleration, peak chest deflection, or the Viscous Criterion (V×C) advanced by one or more non-NHTSA researchers, provided a measure of prediction of injury outcome, a formulation that included both peak chest acceleration and maximum chest deflection, called the Combined Thoracic Index (CTI) appeared to provide superior predictive capability compared to all others examined. The formulation of the CTI is:

$$CTI = \frac{A_{max}}{A_{int}} + \frac{D_{max}}{D_{int}} \tag{2}$$

where Amax and Dmax are the maximum observed acceleration and deflection, and Aint and Dint are the corresponding maximum allowable intercept values (Salwani et al., 2014).

4.16 NGV crashworthiness and occupant safety systems

The principles of crashworthiness and occupant safety have been well described in foundation research studies such as the original Grzebieta publications (Grzebieta et al., 2017) and more recently Tingvall's landmark vision (Gaylor and Junge, 2017). There is extensive engineering literature on the principles behind crashworthiness and occupant protection. These principles are reviewed in both the Hussain et al., (2019) and Levick & Grzebieta (2007) research studies which address these fundamental approaches that underpin the analysis undertaken in this research. Design Principles for Injury Mitigation upon Impact:

I. Reduce the exchange of energy
II. Provide energy absorption (maximize the stopping distance)
III. Ensure compatible interfaces
IV. Manage the exchange of energy
V. Provide a survival space

Based on the above design principles, and the extensive body of automotive safety literature and existing real world VAN crash data, in addition to any dynamic or impact test data for similar VAN design and performance. The analysis is one based on these principles and is supported by evidence using the simulation VAN model VAN and crash test data that is available.

4.17 Optimization method for tank location layout

Approximate optimization strategies are able to overcome the difficulties encountered in optimum crashworthiness design. Especially, multipoint approximations that do not use sensitivities are suitable to deal with both the computationally expensive numerical analysis and the non-smooth optimization problem. The basic principle is to generate approximations of objective function and constraints in a certain part of the design space, and to solve the optimum point for this approximate optimization problem. The approximate optimization problem is smooth and explicitly known, and can be easily solved using a standard mathematical programming algorithm. Using the global concept, approximation models of objective function and constraints are built that create an explicitly known approximate optimization problem in the complete design space or a large part of it. To generate global approximations, often response-surface techniques are used (Venter et al., 1998). Response-surface model building starts with postulating the approximate model functions. Then, an experimental design is selected defining the set of the design points for which computer experiments are carried out. Finally, regression analysis is used to estimate the unknown parameters of the approximate models by fitting the numerical response data. Etman et al., (1996) and Venter et al., (1998) constructed global response-surface models for crashworthiness design problems. However, response-surface model building is an iterative and highly user-interactive process. The selection of appropriate model functions is often rather difficult. Additionally, the number of analyses increases exponentially for growing number of design variables or more elaborate model functions.

4.18 Description of CNG Vehicle System

Generally, CNG fuel systems are relatively simple in terms of their mechanical and electrical/electronic components. The complexity of natural gas/gasoline systems and more often with heavy duty, dual-fuel natural gas/diesel vehicles relates mostly to the fuel management system and its compatibility with the controls designed for petroleum fuels. The NGV system components are type approved and installed in accordance with UN/ECE Regulations 110. These components include: One or multiple CNG cylinders, also including thermal/pressure relief devices (PRDs), excess flow valves, manual valves, and brackets or frames for multiple cylinders comprising the ‘fuel storage system’; High pressure fuel lines; Pressure regulator, fuel solenoid valves (one for a gas line/one for petrol) and fuel injector(s). A schematic of the basic CNG fuel system, along with some of the principle international standards and regulations applicable to the components is shown in Fig. 3.

4.19 GAS Tank Composition

Chen and Pan (2013) focused on the performance of a compressed natural gas (CNG) cylinder with hoop wrapped composite layer to check the axial crack at the inner surface. Using a finite element method, they monitored the stress intensity along the crack front. They also discussed the cylinder geometry, hoop wrapped layer thickness and the property distributions of the composite layer on the stress intensity factor. Yue and Li (2012) argued that defects in composite of CNG cylinders in motor vehicles cause drawbacks as crazes and cracks in cylinder liners. To solve this problem they used ANSYS to simulate various composite CNG cylinders. Then a top-down modeling is used to obtain the cloud diagrams of stress and strain under operating pressure, test pressure and bursting pressure. Mirzaei et al., (2013) focused on the catastrophic failures of CNG fuel tanks. Their experiments show an internal gaseous combustion. Therefore, they carried out a series of transient-dynamic elasto-plastic FE analyses to check the performance of the gas tank while facing a special type of combustion-induced dynamic pressure. Bhattacharjee et al., (2010) analyzed an accident that happened in India as a result of bursting of a compressed natural gas (CNG) cylinder. They considered both technical and human factors that caused the accident. Lie and Li (2014) proposed a new method for predicting failure pressure of a cracked Type 1 full metal CNG cylinder. In continuation, using charpy impact and tensile coupon tests and crack tip opening displacement they measured the fracture toughness and stress–strain curve of the metal. Their findings showed that in real conditions it is safe to use Level 2A FAD curve to predict the failure pressure of a Type 1 full metal cracked CNG cylinder. Shamsudeen et al., (2014) used finite element analysis for design and simulation stress and displacement for the cylinder head with CNG direct injection in a range between 1000 and 5400 rpm. Their results showed an improvement for the CNGDI cylinder head in terms of stress and displacement.

4.20 Safety of CNG and Cylinder Types

Safety concerns of NGVs most typically reflect issues with the high pressure fuel storage systems. In fact, CNG fuel storage systems are amongst the safest, most robust of any transportation fuel used today. Likewise, CNG cylinders are subject to the most stringent, destructive, and challenging certification testing requirements than those of any liquid fuels. Steel cylinders are tested to 2.5 times the working pressure and as much as 3.65 times the working pressure for CNG cylinders incorporating or made of various composite materials. Emergency shut-off devices and pressure relief devices are specially designed and installed to maximize safety in the event of an accident or other unforeseen occurrence harmful to the vehicle. Compressed natural gas (CNG) cylinders are available in a number of different types, weights and sizes to suit different applications. These include:

- CNG Type 1: All metal cylinders made of steel. There is no covering other than paint on the outside of the cylinder.
- CNG Type 2: A metal cylinder (steel or aluminum) with a partial wrapping that goes around the cylindrical part of the cylinder (hoop wrapped). The wrapping is usually made of glass, aramid or carbon fiber, contained in an epoxy or polyester resin.
- CNG Type 3: This type of cylinder is fully wrapped with the same kind of material used for the partial wrapping of a Type 2 cylinder. It has a metal liner, usually an aluminum alloy.
- CNG Type 4: This is fully wrapped with the same kind of material used for the partial wrapping of a Type 2 cylinder. This type of cylinder has a plastic liner.

Specific requirements set out in international standards and regulations specific to CNG fuel systems “are based on the unique physical and chemical attributes of CNG.
Specifically for safety considerations, these typically have requirements to include (but are not necessarily limited to):

I. Requirements for minimum structural integrity and labelling of high-pressure CNG fuel containers;
II. A PRD (pressure relief device) is a one-time-use device triggered by excessive temperature and/or pressure that vents gas to protect the cylinder from rupture, particularly in case of a fire. Temperature-triggered PRDs are mandatory; pressure triggered PRDs are optional.
III. Requirements related to sizing, securement, routing, and protection of PRD vent lines to protect vehicle occupants from—and to minimize—the possibility of venting gas being ignited;
IV. A manual or remotely activated shutoff valve on each CNG fuel container to isolate it from the rest of the fuel system;
V. An additional shutoff valve to isolate all CNG fuel containers from the rest of the fuel system and engine.”
VI. An excess flow valve to shut off or extremely limit the flow of gas escaping from a container in case of a ruptured pipe or main valve.

As with road vehicles of all types, ensure proper installation and regular inspections of fuel system components (lines, valves) can preclude in-use wear and damage.

4.21 Fuel component

Yusaf et al., (2010) developed a model to predict brake power, torque, brake specific fuel consumption. Their research also investigates the exhaust emissions of a diesel engine modified to operate with a combination of both compressed natural gas CNG and diesel fuels. They employed artificial neural networks to solve their model. As a result they designed a cylinder. The findings show that the mixtures of CNG and diesel fuel provided better engine performance and improved the emission characteristics compared with the pure diesel fuel. Khan and Yasmin (2014) focus on increasing natural CNG demand in Pakistan which shows a tremendous growth in recent years. Hence, they formulated a new Compressed Natural Gas (CNG) which is more environment friendly than natural CNG. Subramanian et al., (2013) evaluated an automotive spark ignition vehicle fueled with the methane enriched biogas (93% CH_4) and base CNG (89.14%) in terms of fuel economy and mass emission. The results showed that the vehicle's emission with the enriched biogas fuel meets the BS IV Emission Norms. They also found that since the performance of the methane enriched biogas and fossil CNG are similar, methane can be used as for spark ignition vehicles. Karabektas et al., (2014) argued that CNG causes poor performance and emissions in vehicle engines. Therefore they proposed using natural gas in a diesel engine as a dual fuel, and investigated the effects of employing diethyl ether. Their result shows that use of dual fuel yields higher CO and HC emissions along with lower NO emissions expect for high loads. Furthermore, the use of additives leads to an improvement in brake thermal efficiency and specific energy consumption, while causing lower CO and NO emissions.

Wilmer et al., (2013) measured Methane adsorption isotherms in 0.1–58 bar pressure range and repeated over twelve cycles. The results indicated no detectable degradation. The findings also showed adsorption of CO_2 and H_2 over a broad range of pressures and temperatures. Xu et al., (2010) developed an electronic-controlled single-cylinder engine fueled with CNG and natural gas–hydrogen blends, respectively. They found that the performance of the engine increases while replacing the CNG with hydrogen/methane blend fuels as well as decreasing in effects of excess air ratio and spark timing. Ryu (2013b) designed a compression ignition engine with a dual fuel combustion system by focusing on combustion and emissions characteristics. They found that biodiesel CNG resulted in relatively high CO and HC causes no significant trend of HC emissions with variations of pilot injection timing and at the same time emissions remained at low load conditions due to the low combustion temperature of CNG. M Farzaneh-Gord et al., (2014) carried out a theoretical analysis to find effects of the natural gas composition on the filling process of an on-board NGV cylinder. The contribution of their model is to find the fast-fill process occurring in CNG fueled vehicle storage cylinders. Their outcomes show that the compositions of natural gas have great effects on the filling process and final in-cylinder conditions. Jee et al., (2011) focused on acoustic emission parameters involved in a burst test for a CNG-vehicle fuel tank. Their system includes a resonant sensor which is installed on the center of the fuel tank. Ryu (2013a) studied Biodiesel–compressed CNG dual fuel combustion system to find out the amount of reducing particulate matter and nitrogen oxides from diesel engines. The findings indicated that mean effective pressure of the proposed system is lower than what is gained by diesel single fuel combustion at higher injection pressure.

Roy et al., (2014a) addressed a model for evaluating the performance and emission parameters of a CNG-diesel dual-fuel mode single cylinder four-stroke engine. One novel aspect of their work is using artificial neural networks as a base for comparing the results with.
Ramjee & Reddy (2011) focused on a CNG as an alternative fuel to overcome depletion of petroleum products and its major contribution for pollutants. They found that in a higher compression ratio with more octane CNG allows the combustion without knocking. Moreover emission characteristics of HC and CO are found lesser while using CNG than what is in petrol.

Ma et al., (2010) investigated effects of high hydrogen volumetric on performance and emission characteristics in a turbocharged LNG engine. For this purpose a number of experiments are carried out considering different operating conditions including different spark timing, excess air ratio and manifold pressure. They found that surplus values of hydrogen at high volumetric ratio could significantly extend the lean burn limit and improve the engine lean burn ability consequently. Moreover it could decrease the burn cycle and causes higher thermal efficiency accordingly. To measure the emissions, CO, methane and NOx are measured and it is found that in the mentioned condition the values of CO and methane are decreased while the values of NOx remained constant. Mohsin et al., (2014) studied the performance of an engine that used biodiesel fuel in terms of measuring the air emissions. They believed that biodiesel fuels are renewable fuels which causes fewer emissions and can be replaced with fossil fuels. In their experiments, they combined CNG with biodiesel fuel called biodiesel-CNG. Their results showed that the offered fuel provides lesser exhaust emission and moreover it can provide better horse power in the studied cases. One novel aspect of their research is that they found biodiesel fuels can be used in cars without any engine modifications. Lim et al., (2012) CNG/diesel dual-fuel engine is using CNG as a main fuel, and injects diesel only a little as an ignition priming. They proposed a new model for transferring diesel engines into dual-fuel engines. The new model could inject diesel with high pressure by Common Rail Direct Injection and then inject CNG for premixing. The outcome indicated that the new dual-fuel engine can successfully improve the operating rates. Moreover the amounts of emissions like CO_2 are decreased. Shanmugam et al., (2010) is also discussed over using fossil fuels which can cause dismissing such natural fuels. They argued that LPG and CNG are suitable resources that should be replaced with fossil fuels. Shah et al., (2011) reviewed dual-fuel technologies, their limitations and drawbacks. In continuation they proposed a new mechanism for using dual fuel engines. Then they also carried out a parametric research over different engine-operating variables that are affecting performance of diesel-CNG dual-fuel engines. Thereafter the effects of gas supplement ratio on emission are discussed with the aim of evaluating the engine behavior under dual-fuel operating mode. Dahodwala et al., (2014) focused on emissions that emerged while using CNGs. They argued that it is important to notice all emissions including PM, CO2, CO and NOX and THC. For this purpose, they focused on the emissions and performance impact of operating a heavy-duty diesel engine while using dual fuel mode. Their design included a mixer to improve the distribution of gas prior to delivery to the cylinder. The results showed the ability to maximize substitution of diesel with CNG across the operating map was limited by extremely high THC levels, combustion instability and limitations in peak cylinder pressure and exhaust gas temperature. Darade and Dalu (2013) evaluated the performance and the emission level of LPG and gasoline in a single cylinder four stroke 257cc VCR spark ignition engine. The outcomes showed that the best performance is observed and efficiency and brake specific fuel consumption for CNG are improved. The results also showed that the emissions of hydrocarbons, CO and CO2 are better than LPG and Gasoline which shows the superiority of CNG. Roy et al., (2014b) compared CRDI coupled CNG with BDO of a single cylinder diesel engine in terms of emissions like PM, NOX and BSFC. Then, a parametric design space is carried out to investigate the possibility of obtaining superior emission performance trade-off characteristics. In continuing using the full factorial method a model is developed that helps optimizing study within the same experimental range of the input/control variables. Finally an adaptive merit function is employed as an objective function to be optimized and an ANN based meta-model is addressed to correlate the objective function with the chosen control variables. Malakoutirad et al., (2015) explained that an engine integral reciprocating NG compressor has the capability to disrupt the incumbent CNG. In their research they proposed an automotive engine-integral reciprocating NG compressor to pressurize storage tanks in NG vehicles from a low-pressure NG. In this regard they used engine cylinders as a multi-stage reciprocating compressor. The findings showed an increase in temperature of the storage tank and engine. Chougule et al., (2013) designed a gas mixer venture and simulated a dual fuel engine that worked by Diesel-CNG. For this purpose they converted a diesel engine to a dual fuel (Diesel-CNG) keeping the same compression ratio with improved fuel economy. In continuation experimental testing is conducted for base diesel engine on engine dynamo for performance parameters and GT-Suite is calibrated. Then the dual fuel (Diesel-CNG) engine is simulated using GT-Power. The results are then compared with diesel engine simulation results.

4.22 Gas tank design and location/ injecting system

For the design and optimization of an engine adopted with CNG fuel, it is necessary to investigate the spray development process, the ignition performance and shape and location of the gas tank. Milojevic & Pesic (2012) focused on the problem of mounting a gas rack with CNG cylinders on the roof of a retrofitted city bus, according to UN ECE Regulation No. 110 to improve safety of the vehicle in city transport. They argued that this problem is a major concern since stress will be increased as a result of mass volume and also the function of the supply of CNG from the cylinders to the engine. Jahirul et al., (2010) focused on the engine performance and exhaust emission on using gasoline and compressed natural gas (CNG). As a result they designed a new 1.6 L, 4-cylinder petrol engine which could be worked by a computer incorporated bi-fuel system which operated with either gasoline or CNG using an electronically controlled solenoid actuated valve mechanism. Their results show that the proposed system could provide fewer air pollution compared to petrol based engines. Chandra et al., (2011) converted a 5.9 kW stationary diesel engine into spark ignition mode that is working with enriched biogas natural gas (CNG). The performance of the engine with 12.65 compression ratios was evaluated at 30°, 35° and 40° ignition advance of TDC. Results showed similar performance while using the new fuel. HUANG et al., (2010) focused on the impact of CNG cylinders on whirlwind turning, mobile location for tools' change. Scheffler et al., (2011) reported the results of 11 years of safe working in the SAE Fuel Cell Vehicle (FCV) Group. They argued that during the last years many activities have been carried out to increase the standard of the vehicular hydrogen systems. Hence they focused on increasing the safety of the gas tanks with the major focus on a small or localized fire that could damage the container. They also developed a new system level test to address the potential failure mode. Hua et al., (2011) compared the performance and cost of compressed hydrogen storage tank systems. The on board and off board performances were determined for compressed hydrogen tanks with design pressures between 5000 and 10,000 psi. They found that the 5000 psi compressed storage system has the potential to meet the targets of the years 2010 to 2015. Mahmood Farzaneh-Gord & Branch (2011) argued that accurate modeling of the fast-fill dynamics occurring in Compressed Natural Gas (CNG) fueled vehicle storage cylinders is a complex process. Hence, a numerical method is developed by converting the mass, real and ideal gas to study the fast filling process of a gas vehicle cylinder.

Naganuma and Ishikawa (2011) argued that leaking hydrogen from a hydrogen cylinder has a lower specific gravity than air. Therefore it could rise in a cylinder housing space and consequently reaches to the upper surface of a roof cover and passes upward and goes outside. Srivastava & Agarwal (2014) focused on the usage of laser ignition in spark ignition engines. In this research, performances of spark and laser ignition systems are compared based on in-cylinder pressure variation, combustion stability, fuel consumption, power output and exhaust emissions. Liu et al., (2013) focused on the location of spark plug and injector. In this regard, they proposed a combustion chamber with a visualization that worked with CNG using a gasoline direct injector which yields spark plug ignition. They found that close positions of injector and spark plug causes a stratified charge of CNG around the spark position.

Kim and Choi (2013) studied the roots of vessel failure of CNG systems in formal inspection and engineering test procedures. To do this, the failure mechanism identified using fractography and the material properties of a reference part will be investigated through the instrumented indentation technique. Using the finite element the authors validated the pressure vessel of composite. Mahmood Farzaneh-Gord & Branch (2011) focused on storing CNG in storage tanks in CNG stations. So, considering the first and second thermodynamics laws they carried out a theoretical analysis to find the effects of reservation on performance of CNG filling stations and filling process. They found that depending on the NGV cylinder in a vehicle, each of the available storage systems may have advantages to the other. Semin et al., (2010) studied converting diesel engines to CNG engines in terms of engine cylinder pressure performance. For this purpose GT-Power computational engines used for simulation. They designed an engine computational model based on the diesel engine which converted to port injection CNG engine. The outcomes showed that conversion development caused decreasing the pressure in the engine cylinder. Mohammed et al., (2011) investigated the performance of a CNG-DI engine while adding amounts of hydrogen to the CNG. The results showed that by optimizing the system parameters, maximum brake torque are observed. Li et al., (2014) formulated a new porous metal–organic framework by optimizing the methane volume which resulted at high working capacity. Douailler et al., (2011) suggested a new method by using direct injection to spark ignition engines that is derived from a diesel engine core and dedicated to CNG combustion. For this purpose a new cylinder is designed to optimize the combustion velocity thanks in terms of fuel mixing and tumble level. To do this, they developed a graphical model first and then using simulation a number of injection tests are done. Then the best design is chosen and manufactured and installed on a single cylinder engine. In continuation they compared the performance of CNG port injection and CNG direct injection configurations and then the test bench results were used to construct a numerical model of a multi-cylinder engine with less emissions. Echter et al., (2014) proposed a new cylinder of CNG engine to allow A CNG vehicle to refuel itself quickly and cheaply. Their main idea was to design home natural gas vehicles. The research contains early design, analysis and simulation work and prototype design. Baratta et al., (2012) designed a combustion system for a single fuel CNG based turbo engine by focusing on performance, fuel economy and emissions. For this purpose a numerical and experimental analysis are carried out. Then the proposed mechanism is optimized in terms of operating conditions that is done by simulating CNG injection, jet formation and air-fuel mixing. The fuel injection process is simulated by means of the virtual injector and combustion system is optimized in terms of the performance and emissions of a multi-cylinder engine.

Jemni et al., (2011) argued that improving combustion is directly related to increasing the performance of the intake aerodynamic movements. Hence they focused on the geometry effects of two intake manifolds on the in-cylinder flow numerically and experimentally. For this purpose they designed a 6 cylinder engine. This engine was modified to bi-fuel spark ignition engine gasoline and gas fueling. In continuation a 3 dimensional numerical modeling is proposed including turbulent in-cylinder flow through the two manifolds. Their outcomes showed improvements in brake power, brake torque and brake thermal efficiency. Douailler et al., (2011) focused on designing a direct injection spark ignition engine where diesel engine is considered as a base and dedicated to CNG combustion using a new cylinder design and the piston crown. Such method helps optimizing the combustion velocity using a high tumble level and good mixing. Their results showed that comparing CNG port injection and CNG direct injection the superiority of potential of direct injection in terms of later injection timings that lead to higher volumetric efficiency. In addition it causes later spark ignition timings that resulted in higher burning speed. Moreover simulations show that DI CNG-engine- shown a 27% reduction of CO_2 emissions. Carbonari et al., (2011) focused on shape optimization of axisymmetric pressure vessels considering an integrated approach where the entire pressure vessel model is developed to minimize the von-Mises mechanical stress from nozzle to head. They argued that better shapes may contribute to a better understanding of the actual influence of shape in the behavior of pressure vessels. Shinde (2012) developed a new mechanism for improving mixing of CNG and air in the combustion chamber. For this purpose they use pressurized flow of CNG inside the cylinder with the help of CNG injector through the intake port. The outcomes showed that the modified mechanism helps improve Brake torque, Brake power, BMEP, BSFC, and Exhaust gas temperature. Eichhorn et al., (2013) focused on CO_2 emissions limits of engine fuel. They also argued that the total number of cylinders per engine has to be reduced to keep the thermodynamic disadvantages of a small combustion chamber layout as small as possible. Then they proposed a turbocharged 2-cylinder engine was designed that allows for several different engine layouts which can be examined and evaluated. Their research also compared gasoline direct injection, gasoline advanced port fuel injection and CNG port fuel injection. Baratta et al., (2010) proposed a direct injection CNG engine with the aim of finding new solutions for the automotive market and fruitful knowledge exchange. In addition, focusing on nozzle configuration is another aspect of their research. In their model, the injector was fed by 2 series of holes. In continuation they simulated their model to determine the number and best location of the feeding holes number to obtain mass fuel flow. Their findings showed that the whole number and the exact place of them play key roles in optimizing the mass fuel flow. Han et al., (2014) proposed a new design for CNG dispenser. The system includes ARM11 core-board as hardware, an expansion board, and a software design based on the embedded Linux system.

In addition as a general function for filling CNG, the system has GUI designed for touch input and an embedded database. Wheeler et al., (2013) addressed an engine design portion of combustion controls enabling systems and solutions to improve fuel economy in a gasoline fueled light-duty vehicle by utilizing gasoline turbocharged direct-injection (GTDI) technology. For this purpose they used one dimensional modeling which helps find the optimum valve lift profiles, compression ratio and boosting configuration. Elgin et al., (2014) discussed about 3 modes where in the first mode the engine cylinders fire provide locomotion for the NGV. In the next mode, one cylinder of the engine is used to compress residential natural gas to CNG vehicle storage tank pressure of 250 bars. In the 3rd mode, one cylinder is compressing NGV that is powered by natural gas combustion in the remaining engine cylinders. The authors designed an internal combustion engine for use in NGV and described the engine dynamometer testing that was used to validate the bimodal engine that provided a compression ignition engine which is powered by an AC motor while pumping air into storage tanks. Table 2 compares the opted researches in terms of contribution, fuel and design.

4.23 Euro-NCAP description

A form of destructive crash test is usually performed in a crash analysis test to ensure safe design standards in crashworthiness and compatibility for various modes of transportation or related systems and components is considered. During the test preparation, vehicle manufacturers are encouraged to liaise with the laboratory and to check that they are satisfied with the way cars are set up for testing. Where a manufacturer feels that a particular item should be altered, they should ask the laboratory staff to make any necessary changes. Manufacturers are forbidden from making changes to any parameter that will influence the test, such as dummy positioning, vehicle setting, laboratory environment etc. It is the responsibility of the test laboratory to ensure that any requested changes satisfy the requirements of Euro NCAP. Where a disagreement exists between the laboratory and manufacturer, the Euro NCAP secretariat should be informed immediately to pass final judgment. Where the laboratory staff suspect that a manufacturer has interfered with any of the setup, the manufacturer's representative should be warned that they are not allowed to do so themselves.

4.24 Passenger Anthropometric Measurements Space

Anthropometric measurements can be used as an index to identify the safe space for driver and passenger. Anthropometric dimensions on drivers and passengers preferred postures were investigated using a multi-adjustable vehicle mock-up with a high number of adjustments and extended ranges. For effective VAN seat design and excellent ergonomics, a certain understanding of the physiology, anatomy, biomechanics and anthropometry of the human sitting position is necessary. There is relatively limited data in Europe on lights good vehicle accidents and these vehicles are yet to be covered by EU Whole Vehicle Type Approval legislation. In-depth work has been carried out in Britain (Lenard et al., 2004) and Germany (Niewöhner et al., 2001) which forms the basis of information in this section.

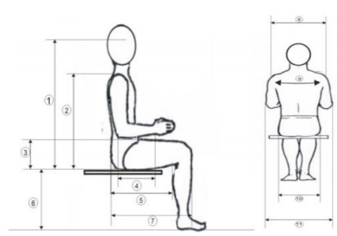

Fig. 5. Anthropometric measurements of males and females according to body heights

However, in this project due to restriction in using dummy passengers and lack of having driver and passenger seats in the available FE model, the residing safe living space has been selected in 3 rows as you can see in Fig. 6 to show the passenger safe space by indicating volumes instead (Table 2). In this simulation the safe living rooms for head, hip and legs are considered according to an average teenage human body.

Table 2. Relevant anthropometric data applicable in automotive seat design (mm)

	Male					Female				
Body Dimension	1st	5th	95th	99th	Mean	1st	5th	95th	99th	Mean
Hip Width	245	282	449	474	340(48)	270	270	475	558	370(60)
Buttock to Potential Length	344	434	580	610	503(48)	330	394	550	580	475(53)
Popliteal Height Sitting	330	381	510	565	458(52)	320	340	510	909	449(210)
Elbow-toElbow Breadth	320	364	583	600	437(58)	316	340	584	650	431(67)
Shoulder Height Sitting	435	510	703	783	589(59)	394	480	670	700	564(62)
Interscye Distance	198	260	427	603	358(79)	230	265	429	489	351(50)
Sitting Elbow Height	130	145	246	434	197(53)	125	149	246	519	203(61)
Elbow-Wrist Length	225	261	345	399	311(31)	200	240	351	450	295(37)
Sitting Eye Height	584	665	870	919	763(66)	595	615	820	860	735(356)
Shoulder Bideltoid Breadth	294	366	524	570	434(55)	325	346	559	650	422(64)
Buttock-Knee Length	432	530	690	704	607(52)	400	490	654	699	586(308)

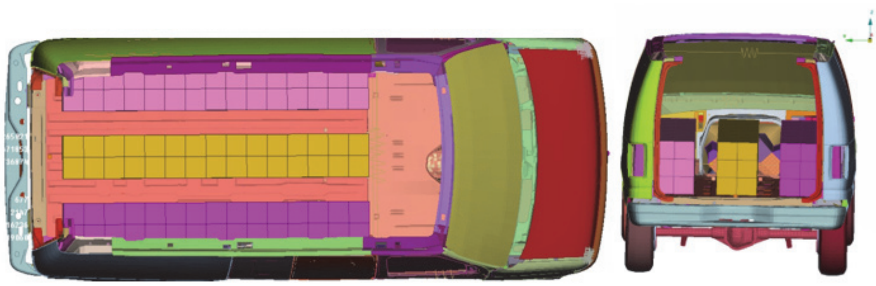

Fig. 6. Passengers reside safety living space

4.25 Head Injury Criteria (HIC)

Vehicle collision can cause mild to severe injuries and even fatality. Statistically, frontal collisions are the main cause of fatality during motor vehicle accidents (Szczęśniak et al., 2014). Common injuries that can be caused by frontal collision are head injuries, thoracic injuries, and internal injuries. Studies on accidental injuries have been reported in many works. Head injury assessment can be made by measuring the Head Injury Criterion (HIC) value, a measure of the likelihood of head injury arising from an impact. In 1998, the Alliance of Automobile Manufacturers proposed the Injury Assessment Reference Value (IARV), a safe limit of the HIC value in the event of an accident, to be set at 700. Head injuries would be unlikely to occur when the HIC15 value is below 700 (Godwin et al., 2010).

$$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t).d(t) \right]^{2.5} .(t_2 - t_1) \right\}_{max} \tag{3}$$

$$a(t) = \sqrt{{a_x}^2 + {a_y}^2 + {a_z}^2} \tag{4}$$

where *a(t)* in Eq. (4) is the head acceleration resultant and t_2-t_1 is the portion of the waveform to be measured during which HIC reaches maximum value (Tables 4 and 5).

Table 3. Comparing the Opted Researches

No.	Reference	Year	Fuel Type				Fuel mode		Contribution		
			CNG	LNG	NGV	Other	Single	Dual	Tank Composite	Fuel Component	Gas Tank/Engine Design
1	Milojevic & Pesic	2012	√				√				√
2	Yusaf et al.	2010	√					√		√	
3	Jahirul et al.	2010	√				√				√
4	Chen & Pan	2013	√				√		√		
5	Chandra et al.	2011	√			√		√			√
6	HUANG et al.	2010	√				√				√
7	Khan & Yasmin	2014	√				√			√	
8	Yue & Li	2012	√				√		√		
9	Scheffler et al.	2011	√				√				√
10	Subramanian et al.	2013	√				√			√	
11	Mirzaei et al.	2013	√				√		√		
12	Karabektas et al.	2014	√					√		√	
13	Wilmer et al.	2013	√				√			√	
14	Hua et al.	2011	√				√				√
16	Bhattacharjee et al.	2010	√				√		√		
17	Mahmood Farzaneh-Gord & Branch	2011	√				√				√
18	Xu et al.	2010	√		√			√		√	
19	Lie & Li	2014	√				√		√		
20	Ryu	2013b	√					√		√	
21	ZHANG & LI	2011	√				√		√		
22	M Farzaneh-Gord et al.	2014	√		√			√		√	
23	Naganuma & Ishikawa	2011	√				√				√
24	Jee et al.	2011	√				√			√	
25	Ryu	2013a	√			√		√		√	
26	Roy, et al.	2014b	√			√		√		√	
27	Srivastava & Agarwal	2014	√				√				√
28	Liu et al.	2013									
29	Ramjee & Reddy	2011	√				√			√	
30	Ma et al.	2010		√			√			√	
31	Mahmood Farzaneh-Gord et al.	2011	√				√				√
32	Mohsin et al.	2014	√			√		√		√	
33	Lim et al.	2012	√			√		√		√	
34	Shanmugam et al.	2010	√	√			√			√	
35	Ismail & Nugroho	2010	√				√				√
36	Mohammed et al.	2011	√				√				√
37	Li et al.	2014	√				√				√
38	Echter et al.	2014	√				√				√
39	Shah et al.	2011	√					√		√	
41	Dahodwala et al.	2014	√					√		√	
42	Baratta et al.	2012	√				√				√
43	Darade & Dalu	2013	√			√		√		√	
44	Jemni et al.	2011	√				√				√
45	Douailler et al.	2011	√				√				√
46	Carbonari et al.	2011	√				√				√
47	Roy et al.	2014a	√			√		√		√	
48	Shinde	2012	√				√				√
49	Malakoutirad et al.	2015	√		√		√			√	
50	Eichhorn et al.	2013	√				√				√
51	Baratta et al.	2010	√				√				√
52	Chougule et al.	2013	√			√		√		√	
53	Han et al.	2014	√				√				√
54	Wheeler et al.	2013				√	√				√
55	Elgin et al.	2014	√		√		√				√
56	Shamsudeen et al.	2014	√				√		√		
57	Kim & Choi	2013	√				√				√

The US National Highway Traffic Safety Administration (NHTSA) final rule specifies the maximum time for calculating the HIC value (t2-t1) as 15 milliseconds (HIC15) (Reimpell et al., 2001). The HIC has been adopted in the design of automotive head protection equipment, such as helmets. This criterion is also used by Federal Motor Vehicle Safety Standard (FMVSS) 214 as one of the criteria to assess head injuries. A study is conducted to find the correlation between HIC values and brain and skull fracture injury levels. The results are shown in Tables 3.2 and 3.3 The HIC has been adopted in the design of automotive head protection equipment, such as helmets. This criterion is also used by Federal Motor Vehicle Safety Standard (FMVSS) 214 as one of the criteria to assess head injuries (Mihradi et al., 2017).

Table 4. Proposed HIC tolerance levels correlated to brain injury

Injury level	Proposed tolerance level HIC_{15}
0 (No concussion)	<150
1 (No concussion)	<150
2 (Mild concussion)	150-500
3 (Severe concussion)	500-1800
0 (Life thretening)	>1800

Table 5. Proposed HIC tolerance levels correlated to Skull fracture

Injury level	Proposed tolerance level HIC_{15}
0 (No fracture)	<500
1 (No fracture)	<500
2 (Minor fracture)	500-900
3 (Major fracture)	900-1800
0 (Life thretening)	>1800

4.26 Internal Energy as a Criterion

There are two main reasons to choose Internal Energy as a criterion:

Firstly, to protect the passenger occupant, it is essential to absorb the energy of collision and convert that into internal energy of the car body after collision. The more internal energy is absorbed by the vehicle body, the more collision energy is vanished so the occupant will be safer with minimum injury. So, internal energy is a parameter to be tested and measured as an important criterion to improve the occupant safety of a VAN. Secondly, LS-DYNA post processing has an option that will give a proper result and graph out the Internal Energy graph manually. As a matter of accuracy and practicality, it is very handy and reliable to work with LS-DYNA to measure the Internal Energy. Internal Energy of the VAN body has no formula to be calculated but it is a kind of parameter to be measured. It corresponds to the amount of energy of the VAN's body and will increase after collision by absorbing the energy of collision. So, the more energy is absorbed the higher increase in the internal energy of the VAN body causing injury and a safer VAN. The goal is to improve the VAN body and apply changes somehow to increase energy absorbance of the VAN body to achieve the highest possible internal energy of the car body after collision.

4.27 LS-DYNA software

For many automotive companies and universities, LS-DYNA is an indispensable tool for understanding the mechanisms associated with the deformation of such complex systems as vehicle structures in a crash. LS-DYNA is used to determine the behavior of a vehicle even before the first prototype is built. As a rule, far more crash scenarios can be investigated numerically than physical tests can be performed. A further benefit is that the time and cost to market can be reduced significantly by applying LS-DYNA which is crucial for product development projects (Delgoshaei et al., 2014). LS-DYNA is equipped with many features specifically designed for automotive applications, e. g. spot welds, airbag models, seat belt models.
The numerous features of LS-DYNA enable the software to be employed in many different fields. A list of common applications related to crash test is given below: - Crashworthiness simulations, -Automotive parts manufacture, - Car bodies, Seats, Roofs, Doors, Hoods, Bumpers, Crash boxes, - Metal forming, - Rolling, - Extrusion, - Forging, - Casting, - Spinning, - Ironing, - Superplastic forming, - Sheet metal stamping, - Metal cutting, - Spot welded, riveted and bolted structures.

4.28 Four reasons why LY-DYNA for crash simulation

There are four main reasons why LS-DYNA has been chosen as the ideal program solver for crash simulation of this research:

First, LS-DYNA is compatible with SolidWorks modeling computer-aided design. As the low option FEA model of VAN in this project (prepared by George Washington University National Crash Analysis Center used in 2017-2020 Model Year Vehicle Program and also in support of several NHTSA programs) is compatible with importing to LD-DYNA. The options deal primarily with the contact of deformable to deformable bodies, single surface contact in deformable bodies and deformable or rigid to rigid body contact. The range of contact surfaces can be defined in LD-DYNA as single surface contact, contact with rigid walls, edge-edge contact, beam-beam contact, contact with CAD surfaces, eroding contact, shell edges tied to shell surfaces and tied surfaces 2-D contact.

Second, LS-DYNA has an extensive element library with both under integrated and fully-integrated element formulations. The lower-order finite elements in LS-DYNA are accurate, efficient, and robust. For the under-integrated shell and solid elements, zero-energy modes are controlled either by viscosity or stiffness hourglass control formulations. The element list includes: -Different solid elements -8-node thick shells -Different 3- and 4-node shells -Beams -Welds -Discrete zero length beams -Trusses and cables -Nodal masses -Lumped inertias -Arbitrary Lagrangian Eulerian elements -Eulerian elements -Element Free Galerkin formulations -SPH elements for 2-D analysis -User-defined elements

Third, LS-DYNA is allowed to structure the design process, explore the design space and compute optimal designs according to specified constraints and objectives of this project. It is used to study the effect location of gas cylinders on crashworthiness and also investigate different impacts of several simulated crashes on passenger safety and analysis of Internal Energy. LS-DYNA provides over 130 metallic and non-metallic material models library, many of them equipped with failure criteria. Materials include: Metals Plastics, Visco-elastic, Elasto-viscoplastic, Glass, Foams, Fabrics, Elastomers and rubbers, Honeycombs, Composites, Concrete and soils, High explosives, Viscous fluids, Biomedical models and User-defined materials.

Finally, LD-DYNA has a built.in option to measure and calculate the Internal Energy and impact of velocity and HIC. This particular option is very important as a matter of accuracy, practicality to calculate the HIC, and measure the Internal Energy as the VAN body right after collision. LS-DYNA's post-processing gives users a simple and quick way to draw graphs for all individual components separately or altogether.

5. Research methology

In the beginning of this section, an approach for simulating the location of the gas tank in the van will be presented. Then each of the Phases of the approach will be explained in detail and the novelties and features of the proposed simulation approach will be explained. In continuation, the software needed for the simulation will be explained based on the Euro-NCAP standards, it is essential to go through Euro-NCAP description and to assign all initial conditions for each impact test for each phase. Meanwhile the method of data gathering and also a brief over evaluating the performance of the proposed simulation method will be explained.

5.1 Validation and verification

The ASME, American Society of Mechanical Engineers, defines the verification as: "The process of determining that a computational model accurately represents the underlying mathematical model and its solution."

Similarly, The Los Alamos National Laboratory (LANL) defines verification as "concerned with identifying and removing errors in the model by comparing numerical solutions to analytical or highly accurate benchmark solutions." This does not imply that verification is just a mechanistic set to checks on the FEA model. The checklist and checking process is a vital part of any traditional analysis plan but, based on the simulation test a few more checks must be done. To verify model representing the real car in the crash test following steps are taken:

5.2 Component check

All components of the car must be checked to be exactly matched with the real car. The following FE model in this research is developed by the George Washington University National Crash Analysis Center and also used in the support of several NHTSA (National Highway Traffic Safety Administration) programs. Ford Econoline is a very popular and effective VAN that plays a key role in public transportation globally and in ASIA PACIFIC including Malaysia.

5.3 Mechanical and physical properties of the components

All mechanical and physical properties of each component must be assigned to the components of the model, based on the real VAN design. After preparing the model of the VAN, the material type of each component is assigned to that component in the model for every single component of the FEA model by its provider "George Washington University National Crash Analysis Center".
LS-DYNA has a wide range of material models, so assigning the mechanical and physical properties of each component is just like assigning the material type to that component meaning when Aluminum, for instance, is assigned to a components all mechanical and physical properties of that particular Aluminum type will be assigned to it.

5.4 The thickness of the components

Apart from the physical and mechanical properties of the components, all components must have the same thickness as the real VAN. After preparing the model of the VAN, the thickness of each component is assigned according to the real VAN.

5.5 The weight of the VAN sample Ford Econoline 2007

The total weight of the VAN without gas cylinders, calculated by LS-DYNA pre-processing, must be the same as the real VAN of 2165Kg. The weight of the modelled VAN has been checked using LS-DYNA as 2214Kg, which is very close to reality.

5.6 Contact between components

Apart from the material type and thickness of the components, contacts between components must be defined for LS-DYNA, otherwise errors will occur in the result and in the simulation process itself. During the side impact test, a trolley with Advanced European Mobile Deformable Barriers face (AE-MDB) with the weight of 1300Kg and trolley initial speed of 50[km/h] was used and the components around the side of crash is deformed and the kinetic energy is transferred to the next components. If the contacts between components are not clearly defined then, after collusion, components will pass through each other which is not correct. All contacts in the model are the VAN have been checked, one by one; and over 30 times running of LS-DYNA processing, all errors are eliminated. After all this preparation, the model is ready to conduct the crash test.

5.7 Visual check

Visual validation of the impact is calculated to evaluate the accuracy and validity of the model. This can simply be witnessed visually when the simulation goes wrong for example when one component passes not as expected. Once all contacts are defined perfectly and all mechanical and physical properties as well as thicknesses are assigned to the components then the simulation test results will perfectly match the real test results. Fig. 7 shows the front view of the Ford Econoline inner parts and inner view of the front body beam compared with the modelled VAN.

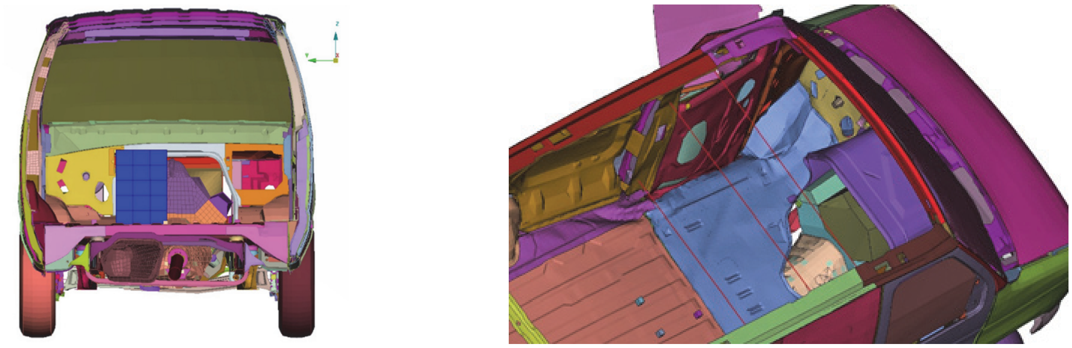

Fig. 7. Inner parts front view (Left Image)/ Ford Econoline front inner body beam parts view (Right Image)

5.8 Initial conditions of the crash test

All initial conditions of the crash simulation test must be in accordance with Euro-NCAP in order that the results are comparable with Euro-NCAP results. The initial conditions for the crash test have been assigned to the model, based on Euro-NCAP specifications which are schematically shown in Fig.8 for front impact and side impact test respectively. The MDB and the rigid wall are also designed and prepared for the front impact and side impact test.

Fig. 8. Front impact (Left Image)/ Side impact (Right Image) based on Euro-NCAP specifications

Validation: The definition of the validation based on ASME (American Society of Mechanical Engineers) is "The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model." Comparing against reality is the best way to ensure that the validation is done by checking the simulation test results against the experiment test results. For example, the research by McGregor et al., (2017) shows the validity of the material model and its calibrated input parameters, the response of notched tensile coupon well with experimental measurements.

5.9 Comparing against reality

To validate the results of the crash simulation test, all data collected from the crash simulation test must be matched with real crash test results. In this case, if only one data of crashworthiness value tested by LD-DYNA matches the real verified as validated based on this match. Many researches have followed this step to validate their simulation result. As an example Golman et al., (2014) have conducted a simulation test to develop a robust methodology to reconstruct injuries sustained in real world crashes using vehicle finite element models, a real world near-side impact crash (CIREN) database. An average similar Passenger Vans was struck at approximately the B-pillar with a 290 degree principal direction of force by AE-MDB and to validate the result, it has been checked against the real crash test.

Fig. 9 shows the simulated side e impact test as well as real impact test on Ford Econoline. As it can be seen, the simulated impact test is fairly matching the experimental side impact test. The photo of the real test has been taken on the 0.04 second after collision where the side door and B-pillar have already deformed. The photo of the simulation has been shot right on the same time, 0.04 second after collision. As it can clearly be seen, the amount of panel dislocation and components deformation in the simulation test is fairly matching the experimental test that is done by NCAP.

Fig. 9. Side impact test (left image), simulated vs real test (right image)

5.10 Energy Balance after crash test

The accuracy of the FEA model is checked by examining the energy pattern exhibited by the simulation results. Following checkpoints are considered for energy balance:

I. The total applied energy should be constant throughout the simulation. Total energy is the sum of kinetic energy and potential energy of the complete system.

II. The kinetic energy should be decreasing and internal energy should be increasing; and ideally the sum of kinetic energy and internal energy should be equal to total energy

III. The Hourglass energy should be less than 5% of total energy.

Hourglass energy is the energy lost due to improper FEA modeling during simplifying the geometry. Below energy pattern is observed during simulation. Fig. 10 shows an example of Front impact comparison of energy balance after a crash test.

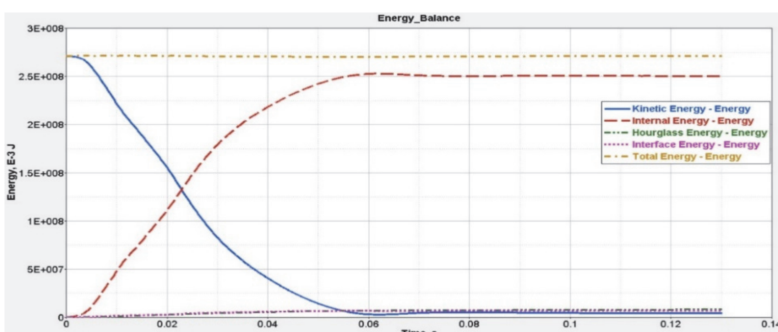

Fig. 10. Front Impact Energy Balance Comparison

5.11 Energy balance Curve

According to the Law of Conservation of Energy, Energy can neither be created nor be destroyed, but it can be converted from one form of energy to another form. Applying the same principle to crash analysis, the amount of kinetic energy lost during impact must be converted to other forms of energy such as internal energy, sliding energy and hourglass energy. It is also noted that, there may be negligible errors in calculating energy ratio because all the processes in this universe are irreversible and some losses are always included which deviates energy ratio slightly from one.

5.12 Kinetic Energy

Kinetic Energy respect to Time and understanding the role of kinetic energy will help to develop measures to reduce the generation, distribution, and effects of this energy during a crash.

$$KE = \frac{1}{2} m v^2 \tag{5}$$

Where KE is energy in joules, m is mass in kilograms and v is velocity in m/s.

In the concept of crash analysis, mass and speed are properties of all the energy that can be transferred during a crash; and the two properties are connected to kinetic (mechanical) energy. The amount of energy interchange can result in injury severity that is equal to one half of the vehicle mass multiplied by the square of the vehicle speed. This means that the kinetic energy during a collision greatly increases due to velocity rather than mass and consequently, small increases in vehicle speed will result in major increases in the risk of injury. In order to have better insight into the amount of energy involved, it should be considered that one Joule is approximately the energy released when a textbook is dropped on the floor. Speed is a well-known key risk factor in the risk of crash occurrence as well as in the severity of an injury. For example, kinetic energy with a motorcycle weighing 150 kg and traveling at 60 km/h speed can produce 270,000 joule, while with a speed of 120 km/h, the same motorcycle can produce 1,080,000 joule. This energy can be transferred in a fraction of second and is the reason why an increase in speed can be harmful or fatal (Khorasani-Zavareh et al., 2015).

5.13 Comparison among NCAP standards

Other NCAP standards are slightly different from EURO-NCAP standards. In Japanese NCAP, for side impact, the test speed is 55 km/h and no child dummies are prescribed. Australian NCAP is similar to EURP-NCAP for side impact. No child dummies are tested in the rear seat. In Latina NCAP there is no side impact test. National Highway Traffic Safety Administration (NHTSA) side impact test procedure is analogous to the FMVSS 214 protocol. The impact velocity in FMSS 14 is 62 km/h and direction is described as 27 degree towards the vehicle. Fig. 11 shows the test required for each standard and each assessment field (Lie & Tingvall, 2002).

	Crash Test	EURO-NCAP	ANCAP	Latina-NCAP	JNCAP	NTHSA
Adjust Occupant Protection	Front Impact	√	√	√	√	√
	Side Impact	√	√		√	
	Pole Impact	√	√		√	
Child Occupant Protection	Front Impact	√	√	√	√	
	Side Impact	√	√		√	
	Pole Impact					
Pedestrain Protection	Leg Form	√	√			
	Upper Leg Form	√	√			
	Child/Adult Head	√	√			
Safety Assist	Driver Assist System	√	√			
	ESC	√	√			
	Speed Limitation	√				
	Intelligent Seatbelt	√	√	√		

Fig. 11. Test required in each standard

5.14 Morphological chart for Internal Energy

To develop mechanical model of internal energy to predict crashworthiness in side, front and rear impact tests assigning various types of condition in each crash test and B-pillar, as objective number three, the first requirement is data collection of the Internal Energies of each crash tests using LS-DYNA post-processing. It gives a graph of Internal Energy versus time for the collision time. The Internal Energy value for each crash test (with and without cylinders) is considered as the maximum value of this graph. After determining the Internal Energy for each crash test with cylinders and comparing it with the same crash test without cylinders, it is possible to compare the effective parameters analysis of the crash to stay within standards. This result can be discussed and developed to select the most effective parameters and delete unnecessary parameters off the final results. This comparison has to be checked against valid data for the verification and validation. To test various crash tests and thickness and investigate their effects on crashworthiness, three cases as crash types in each condition (with and without cylinders installed in VAN chassis) were tested and outcome data we put into the Internal Energy results.

5.15 Methodology Flow

In this section, an appropriate methodology flow will be selected and for this purpose, using the information gathered from the literature review section and the applicable standards for safety of gas tanks. A selected methodology is represented in Fig. 12.

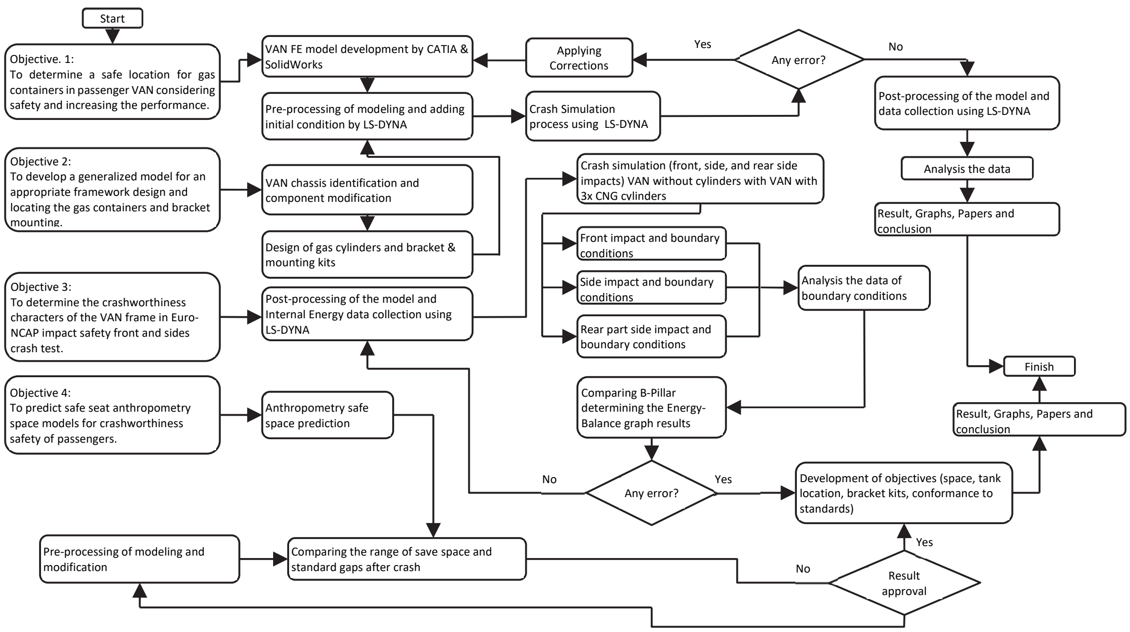

Fig. 12. The flow diagram of the proposed method in details

This method consisted of selecting the vehicle, tanks location optimization, vehicle body architecture, crashworthiness characteristics and assessment, NGV components systems layout and final evaluation. In this step, we will explain the suitable method for conducting this study. The method is inspired from the literature and so it is trustworthy. Moreover, after finishing the tests and getting the results, statistical analysis will be carried out to ensure the effectiveness of the mechanism in different circumstances. As shown by Fig. 12 and according to our findings in section 1, to overcome the problems of air pollution and lack of fossil fuels, it is necessary to use other types of fuels like CNG and bio-fuels. In this regard CNG is considered as an effective fuel both in performance and produced emissions. Using CNG needs to increase the safety of the gas tank. As shown more than 90% of the opted researches in the literature are dealing with the idea of designing or improving the gas tank. For this purpose they used computer simulation. In addition, in many researches for advanced computations the authors used heuristics like fuzzy sets and artificial neural networks (Delgoshaei & Gomes, 2016). They also use 3rd max for designing the gas tanks and used laboratory tests for evaluating the performance of the proposing mechanism.

5.16 Choosing Passenger Van to Simulate: Ford Econoline

The Ford Econoline is an American motor vehicle found in 1998. Since then Ford Econoline has been manufactured in high level production and still there are many people around the world and mainly in the USA who love this motor vehicle. Ford Econoline is manufactured in different types of minivan and minibus, van, pick-up, taxi, and ambulance. In the USA, the Econoline is exclusive to Toyopet Store locations. Fig. 13 shows Ford Econoline in 1998 and the model of 2012. Image is retrieved 18 July 2019 from Ford Motor Company Ltd. Photo gallery. Fig. 14 shows the body shape of Ford Econoline in different views.

Fig. 13. Ford Econoline in 1998 and 2012

Fig. 14. The body shape of Ford Econoline in different views

5.17 Using Solid Works for simulating the van

In order to design the gas cylinder, the Solid Work will be used as a powerful drawing tool that is authorized by UPM. Solid Works is amongst the most powerful software to draw objects. This software is supported by many attributes that enables scientists to use them in order to create powerful designs. In this research, Solid Works is used to draw the van. This drawing has all needed requirements for simulating the van using LS-DYNA. The proposed place for the gas tank is calculated and drawn in the Solid Works. The followings show the steps of drawing the Vehicle and designing the gas tank location inside the van using Solid Works.

5.18 Ford Econoline Body Dimensions

In the first Phase, using Solid Works software, the surrounding space of Chassis and dimensions have been determined and approximate location of Gas cylinders in a CNG Cage protected to fit in the space tire is shown in Fig. 15. Also the space between and sections of the rear tires within the back portion of our sample is illustrated as well as the Chassis sections to clear the view of our design.

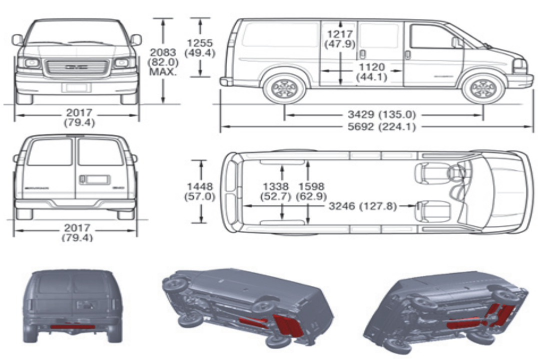

Fig. 15. Dimensions and approximate location of gas cylinders in Ford Econoline

5.18 The Proposed Design of the Shape of the GAS Cylinder

So far, the research investigates the problem statement. The appropriate method for designing the proposed mechanism is chosen by inspiring from the literature. In continuation the body dimension of the Ford Econoline and approximate location of the gas cylinder is drawn by Solid Works software.

In this section and prior to finding the optimum location of the gas cylinder in Ford Econoline, the body shape of the gas cylinder and the composite of the gas cylinder must be designed first. For this purpose, CNGV Body project sample (Ford Econoline) is designed. Then the components and simulation of the installation of this system into the chassis of the project sample (Ford Econoline) will be determined in this Section. The design is focused to enhance these main 2 goals, therefore a bracket is designed with a well-protected shell and bracket mounted inside two frames that can make the circumference of the CNG Cage with high strength when accident occurs or from any scratches. To increase the capacity of CNG storage there are 3 cylinders designed into the CNG Cage that can provide the volume of 124 liters in Fig. 16.

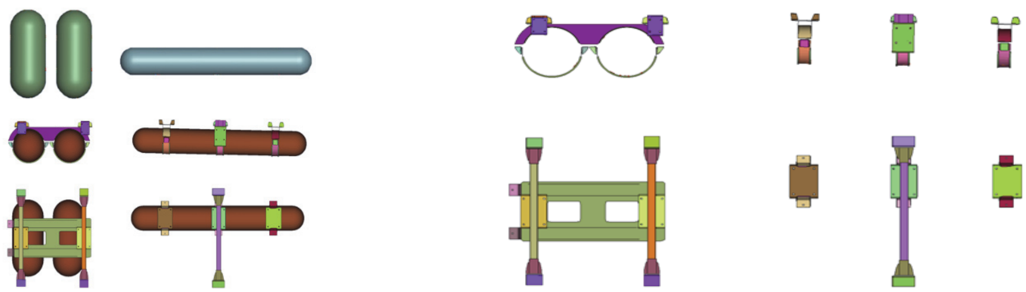

Fig. 16. Design of the proposing Gas Cylinder (Left Image)/ Gas Tank (Right Image)

Furthermore, design of the tanks, cage and the brackets securely maintain pressure and capacity of cylinders to increase the driving distance are the main points to tightness and withstand standard fire tests and is able to enhance technical requirements and prescribed (Fig. 16).

5.19 Computations of designing Gas Cylinder

Using Solid Works the entire component for Safety Cage is designed and dimensions are selected according to the dimension of the chassis in order to increase the sustainability of the chassis in the rear section of the van. Fig. 17 shows the front and side design of the gas tank in Solid Works.

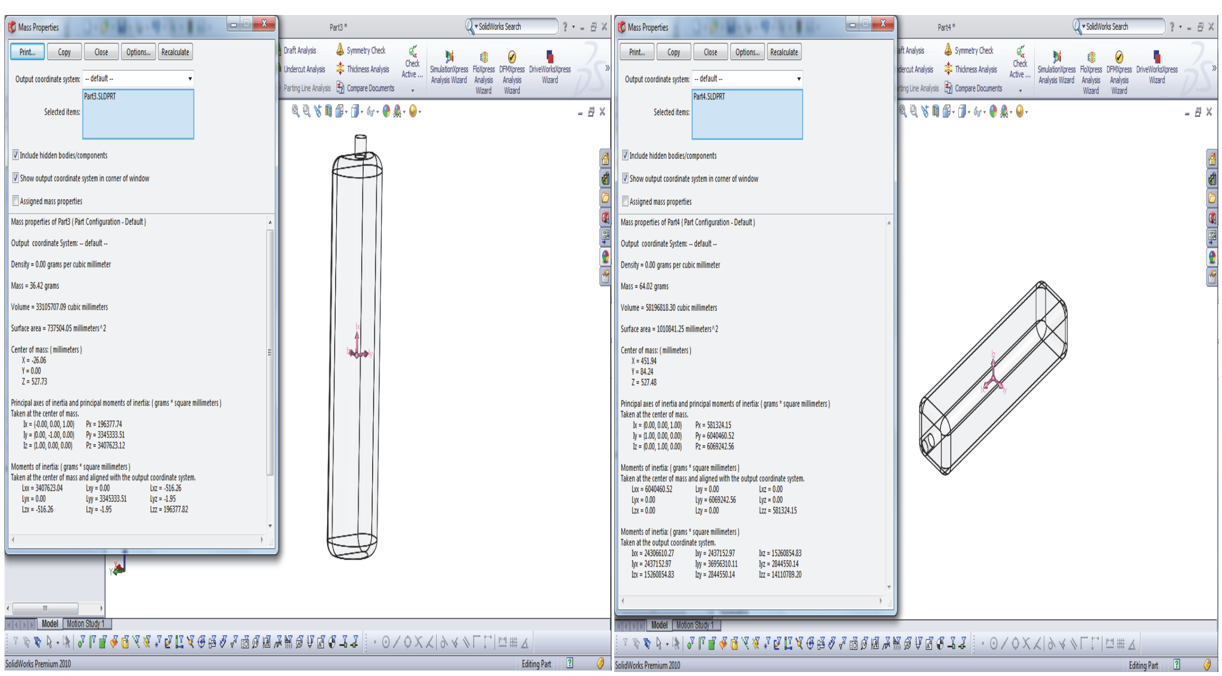

Fig. 17. Design of Gas Cylinder (Front View), left image/Design of Gas Cylinder (ISOMetric View), right image

Fig. 18 shows the safety box that must carry the gas cylinder in order to maximize the protection.

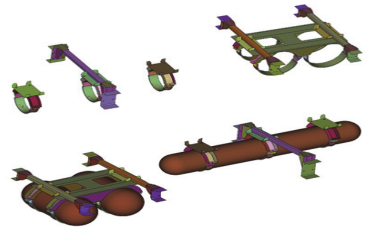

Fig. 18. ISOMertic Section of a Bracket and Mounting for Gas Cylinder

5.19 Calculate the ideal Location of Gas Tank

The Cylinders will be packed into the mounting assembly kit according to the following matter on the chassis on the figures below to fit the space provided in the space above where the Cylinders would be custom fitted in the rear posterior of the chassis into the case. Fig. 19 shows the location of the proposed gas tank in the back trunk of the Ford Econoline.

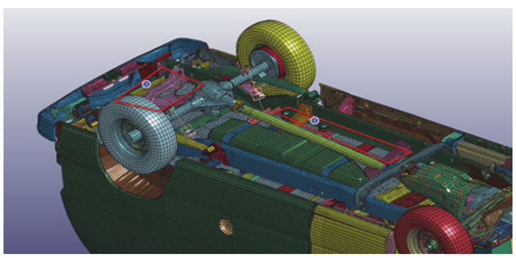

Fig. 19. Proposed location of The Designed Gas tank

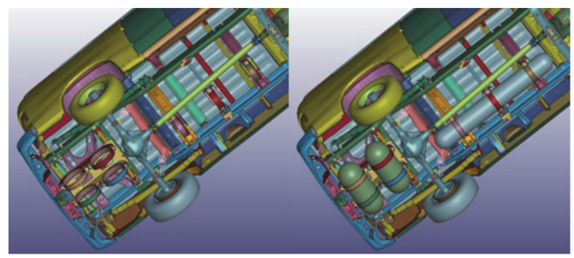

Fig. 20. Final location of the proposed gas tank package in the Ford Econoline

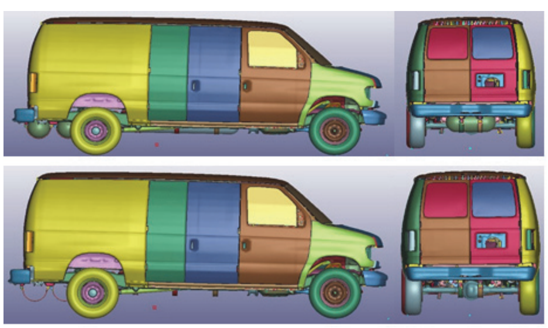

Fig. 21. The proposed gas tank package is installed in the Ford Econoline

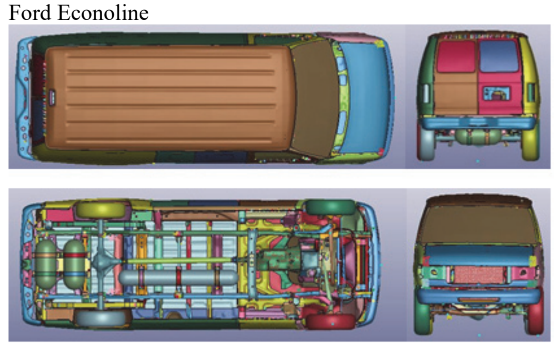

Fig. 22. Final Outlook of Design

The final location is made within the upper and lower frame inside the Chassis (Fig. 20). The protector frames designed to increase the strength of the Chassis and raise the safety protection from the given pressure of accident to the Cage in 4 sides (along the wheel axles and the cross sides) and also from upper and lower sides, the Bracket will be tightly fasten to Chassis and CNG Cage with 8 screws in each side. Fig. 21 shows the final location of the designed gas cylinder pack in the simulation Phase. In the next section, results of producing the prototype of the designed gas cylinder pack and statistical results will be discussed in detail. Fig. 22 shows the outlook of the Ford Econoline after installing the developed Gas tank system.

5.20 Import the plans into LS-Dyna

LS-Dyna that is developed by Livermore Software Technology Corporation is a multi-purpose explicit and implicit finite element and multi-physics program that is used to analyze the nonlinear response of structures. A fully automated contact analyzer covers a wide range of material models. Such ability enables researchers to simulate various ranges of structures. In addition, Ls Dyna provides a base of using the advantages of its powerful analyzing mechanism in simulating complex structures. The software is open source. therefore while the users continue to provide more and more possibilities for the calculation of many complex problems, its core is going to be equipped more and more by using the latest technologies in solving nonlinear transient dynamic finite element analysis (FEA) using explicit time integration. Examples of nonlinear FEA can be considered as changing boundary conditions like the contacts between different parts of a structure; Large deformations; nonlinear materials that do not behave elastically (for example thermoplastic polymers). Note that LS-DYNA enjoys a comprehensive library of materials including Metals, Glass, Plastics, Fabrics, Foams and any other materials that would be defined by the user. Ls Dyna is equipped with “transient dynamic: that refers to high speed analysis of elements where inertial forces are taken into consideration. Typical use of transient dynamics include automotive crash which is the main approach of measuring the efficiency of the method in this research. The crash analyzer includes deformation of chassis, body, seats, airbag, seat belt etc. Besides the transient dynamics can be used for evaluating the explosion of gas tank and finally this ability is useful to check the sheet metal stamping. One positive dominant of LS-DYNA is the ability of importing files from other drawing software like solid works. We will use this ability in the next section to import the plans of the van into Ls Dyna to carry out the crash tests and analyze the results.

5.21 Simulating Capabilities with LS-Dyna

LS-DYNA's has various potentials for simulating the structures. It has many features that can be used to simulate a model with a variety of physical events. An example of a simulation that involves a unique combination of features is the NASA JPL Mars Pathfinder landing. In continue a series of capabilities of LS Dyna that can be used in simulating a gas tank of Ford Econoline crash test is listed:

I. Full 2D & 3D drawings
II. Nonlinear dynamics
III. Rigid body dynamics
IV. Quasi-static simulations
V. Normal modes
VI. Linear statics
VII. FEM-rigid multi-body dynamics coupling (MADYMO, Cal3D)
VIII. Failure analysis
IX. Implicit springback
X. Adaptive remeshing
XI. DEM (Discrete element method)
XII. EFG (Element Free Galerkin)
XIII. Material Library

5.22 Reasons to choose LS-Dyna in this research

LS-DYNA is used by the automotive industry to analyze vehicle designs. LS-DYNA accurately predicts a car's behavior in a collision and the effects of the collision upon the car's occupants. With LS-DYNA, automotive companies and their suppliers can test car designs without having to tool or experimentally test a prototype, thus saving time and expense.

5.23 Simulate the Crash Test for measuring the performance and analysing the results (Crash Test)

In continuation performance of the proposed models in real industries will be evaluated using real data gathered from Ford Econoline in the streets. As a prevision, VANs and more specifically Ford Econoline can be considered as good case studies. Similar to many researches in the literature, after preparing the plans of a van with modified gas location using solid works, they will be tested using crash test in Ls Dyna. For this purpose, the van will be tested in wall crash tests in different directions and different speeds. After each crash, the damage of the body of the car, chases and gas tank will be checked.

Fig. 23 shows an outcome of the crash test. As shown, the vehicle's initial speed is 50 km/h for front crash test and following this the places that are damaged in the body of the van are shown clearly in the images. The same data are analyzed in different crash cases (side) in this simulation.

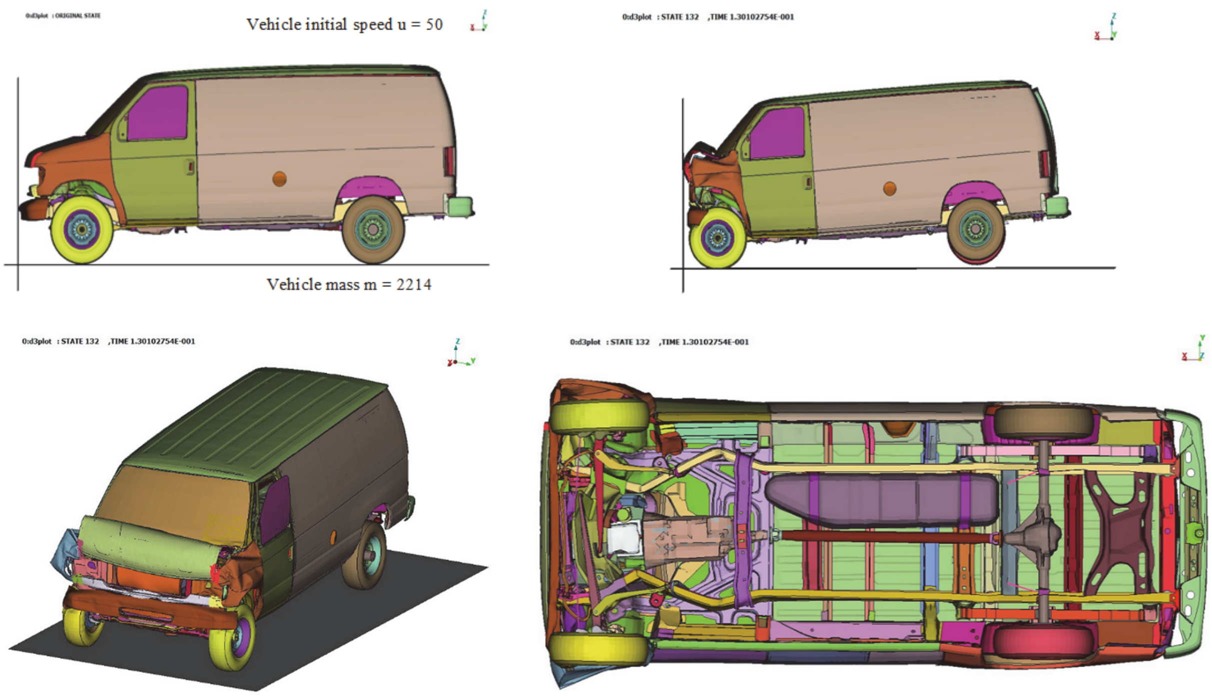

Fig. 23. Front impact- Boundary conditions, (Top Left)/ Side view (Top Right)/ General view (Bottom Left)/ Bottom view (Bottom Right)

5.24 Analyse the Outcomes (Feed back to the stage 2)

After analyzing the crash test by analyzing the gained results, the location of the gas tank will be optimized (Fig. 24).

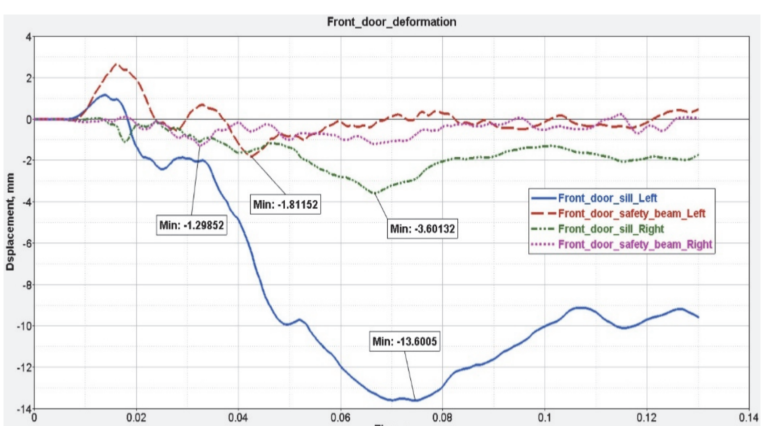

Fig. 24. Results of Crash Worthiness Analysis

Fig. 25. A view of the Gas tank location after side impact

5.25 Personal processor machine specifications

Throughout the calculation process an Intel® Core™ i5 personal laptop will be using which is supported by 2.40 GH CPU and 4 GB RAM and seems to be a powerful processor for drawing 3rd plans and simulating the crash tests.

6. Results and discussion

In this section the result of the simulation of front and side impact test will be presented as the first and second objectives on locating and determining the safest place in chassis for CNG cylinders and bracket kit mounting. Following the third objective will be achieved with analysis of the result of boundary condition after crash test of the VAN frame in EURO-NCAP impact safety boundary. Also analysis and comparing the result regarding the passenger anthropometry safe space to be within the standard range will provide the accepting result to achieve the fourth objective.
The test is performed in six individual cases and two assemblies set up for CNG cylinder in VAN chassis. The first assembly set up would be VAN with no cylinders installed and three crash tests will be performed by LD DYNA and the individual result analysis for each case_ front and side. Second assembly set up would be Van with three CNG cylinders and running the crash test once again in three cases and analyzing the result for each case.

6.1 Brief description of work steps

We can divide the steps of work into two major sections as below:

I. Crash-test simulations (front and side) of VAN without cylinders. As we have no geometry of interior, seats, belt, and passengers – we use a “living space” approach for passenger safety analysis. According to LS Dyna crash test and analysis operators and third-party companies, this approach is quite popular with crash test process faces some restrictions as it was mentioned earlier.
II. Cylinder mounting. During cylinders placement positions search we used a popular layout. In reality it is fairly difficult to add more cylinders than three, considering following the model to locate the CNG cylinders into the “under vehicle” space.

Case 1 - Front Impact

In front impact test, VAN with no cylinder is crashing the rigid wall with the speed of 50 km/h and the main purpose is to clarify the damages to VAN front body and driver and front passenger. Fig 2. Front impacts are shown in three different views which we will analyze in the following section.

Case 1 - Boundary conditions

Front impact boundary will be analyzed after and before crash test with allocating two beam-sensors inside the front door frame of the vehicle as shown in Fig. 3. In this simulation test, the crashworthiness is determined with measuring the parameters below:

Beams-sensors location are installed within the front door frame on the left and right side of the model. The data captured by these sensors are mainly used to measure the displacements data during crash tests for the Front and Side Case.

Points-sensors location are the same way as beam sensors but, the only to assign some spots under the button section of the vehicle in the drive and passenger foot area. The firewall points are chosen based on the crash type in this test. The angel of Trolley used in the test is effective in allocating the firewall spots.

Total Energy-balance graph shows how the internal energy and its positions would be during the test.
Inner body beams-sensors location are also the same way as beams-sensors and located along the vehicle’s body from left to right covering the passenger area. We use three from top, middle and bottom inner beams.

B-Pillar beam-sensors for the front door are used to measure the displacement of the door frame in order to determine the damages and the results are used in analysis of passenger residual space.
The FE model of Ford Econoline that is used in the test is shown in Fig. 26.

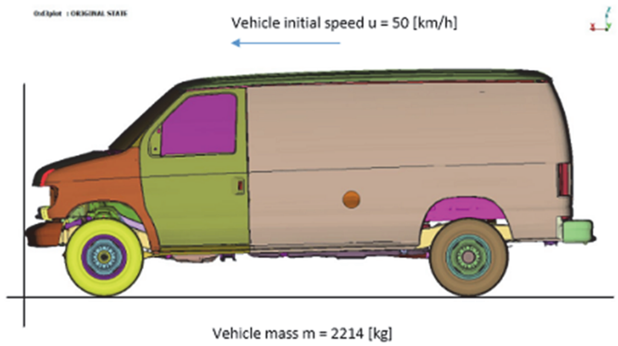

Fig. 26. Front impact - Boundary conditions

Case 1 - Results

The front energy absorption components of the car deforming sufficiently can be seen from Fig. 27. As it is shown the hood is completely bent, tire contacts with fender, bumper and the front longitudinal beam deformation fully Fig. 27.

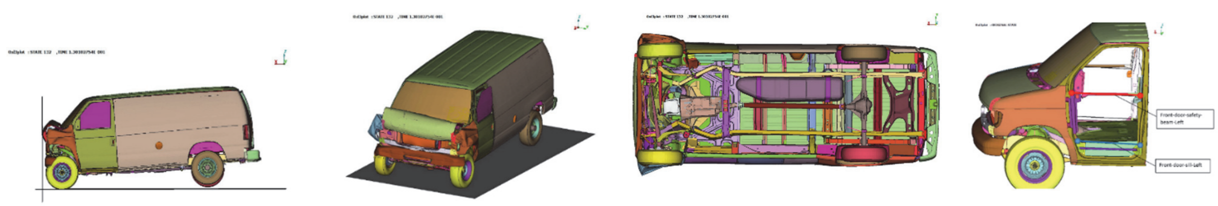

Fig. 27. Front impact - Side view (Top left), Front impact - General view (Top right), Front impact - Bottom view(Down left), Beams-sensor location - Left side (Down right)

Fig. 27 also shows the location of the beams-sensors on the left side, beams on the right side are located on the same principle. Sensors collect displacements data which is effective on crashworthiness analysis. Fig. 28. Is showing the beam-sensors displacements measures after the vehicle collision. The Front door sill- left is having the highest deformation while the rest of the area stays with lowest deformation.

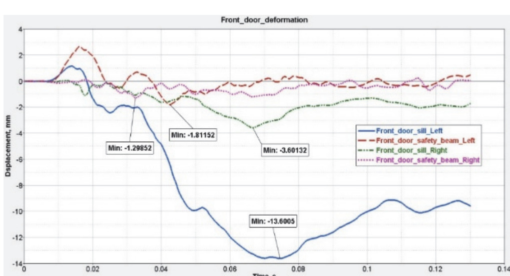

Fig. 28. Beams displacements

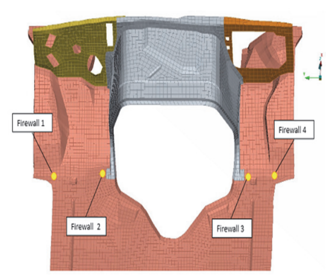

Fig. 29. Points-sensors location for foots displacement analysis

Fig. 29 shows the location of the points-sensors to show space changing in driver and passenger foot area. Fig. 30. Determines the firewall spot displacements measure and deformation pattern in this first 0.13s after the crash occurred. The front longitudinal beam is the main kinetic energy absorber during crash simulation of the vehicle. The ideal front longitudinal beam deformation is that the front of the deformation is sufficient and the rear of the deformation slight, so that the car can efficiently absorb the kinetic energy, avoid high acceleration and prevent dash panel invading largely. It can provide safe space for the driver and front passenger. Fig. 31 shows front longitudinal beam collision deformation and Energy -Balance during different times. As can be seen from Fig. 31 that the front longitudinal beam deforms from the front to the rear with the passage of the time. The front of the front longitudinal beam first happening completely crushing is helpful for the absorption of energy. Over time the center and rear of the front longitudinal beam appearing at different degrees of bending is harmful to the dash panel intrusion.

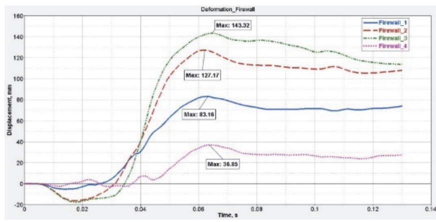

Fig. 30. Points-sensors displacements

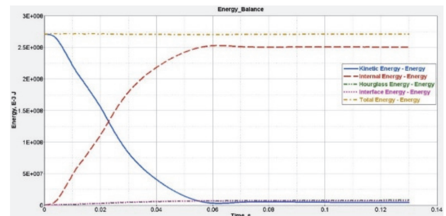

Fig. 31. Case 1 - Front impact - Energy balance

Case 2 - Front Impact - Van with 3 cylinders

Further, description of cases for vehicles with added cylinders. In these numerical calculations, a comparative analysis will be carried out - how the safety of the driver and the passenger of the vehicle has decreased, before and after the addition of the cylinders.

Case 2 - Boundary conditions

The location of the three added cylinders is shown in Fig. 32.

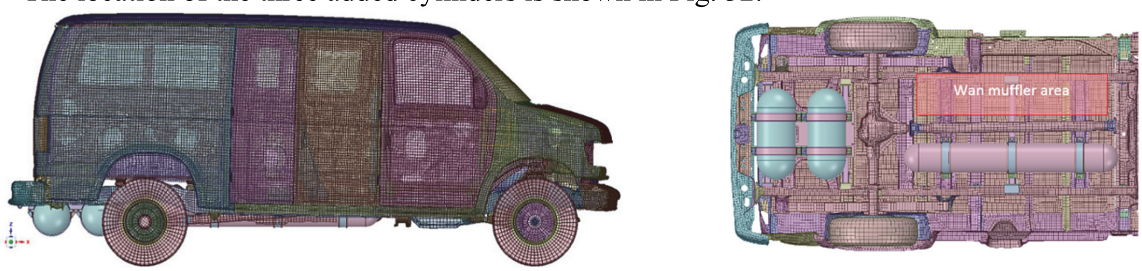

Fig. 32. Cylinders arrangement – Side View (Left Image)/ Bottom View (Right Image)

To the frame of the car were added two cylinders 0.06 m3 and one 0.09 m3. The arrangement of the cylinders chosen taking into account such criteria as:

I. simplicity and cheapness of fastening of cylinders;
II. maintenance of a road clearance of the car for the least decrease in pass ableness of the car;
III. Close arrangement to the center of the car for preservation of stability of the car in bends.

As shown in Fig. 33, the cylinder 0.9 is in place of the fuel tank, which was cleaned. Total weight of the added three CNG cylinders is 225 [kg] to the VAN gross weight during case 2 and case 4. The other elements and parameters are following the same as previous cases.

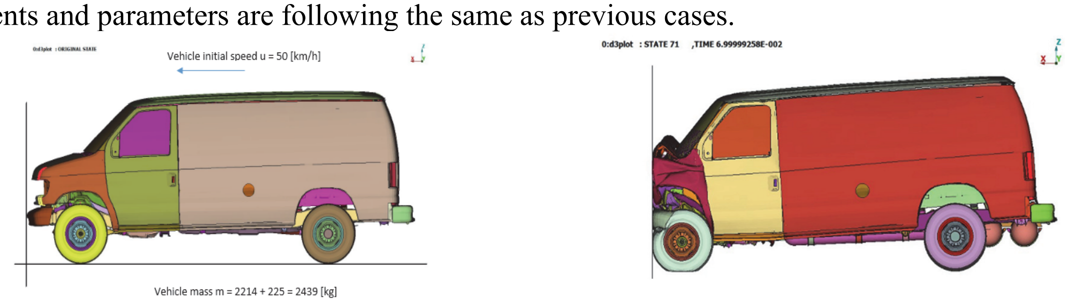

Fig. 33. Front impact - Boundary conditions (left image)/ Side view (right image)

Case 2 - Results

Fig. 34 to Fig. 36 illustrate the crash simulation with CNG cylinder installed.

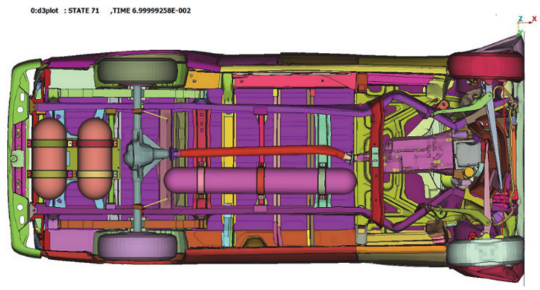

Fig. 34. Front impact- Bottom view

Here is a comparison impact between the same crash type for VAN with and without CNG cylinders installed.

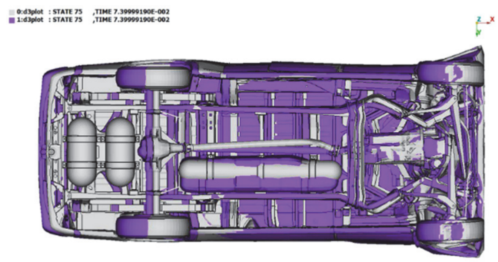

Fig. 35. Front impact - Bottom view - Comparison between Case 1 (Front Impact without cylinders - blue) and Case 4 (Front Impact with cylinders - grey)

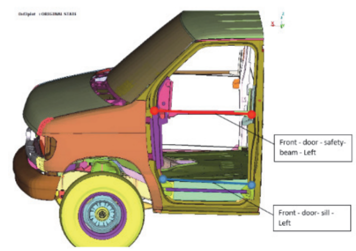

Fig. 36. Beams-sensor location - Left side

Fig. 37 shows the location of the beams-sensors on the left side, beams on the right side are located on the same principle. Fig. 38 shows the front-door deformation during the crash. It determines the highest displacement is still the area of the left door while it can be three times of the deformation on the same area on the right side.

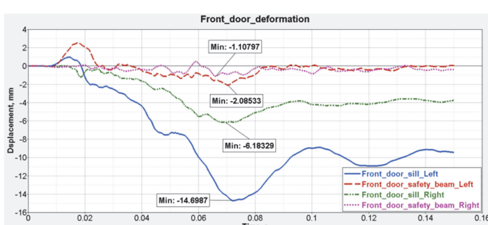

Fig. 37. Beams displacements

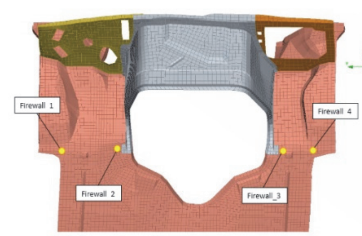

Fig. 38. Points-sensors location for foots displacement analysis

Fig. 38 shows the location of the points-sensors to show space changing in driver and passenger foot area. As it can be observed from Fig. 39, the displacement of firewall 2 is nearly twice of the same in case 1, and firewall3 have also raised in comparison with case 1. Firewall 1 and 4 also have also been raised in their deformation data. The damage effect is slightly raised and that is due to the increase of the total vehicle weight. However, all the result is still within the controlled and save range to have the save passenger residual area.

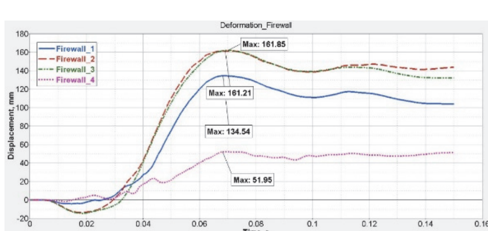

Fig. 39. Points-sensors displacements

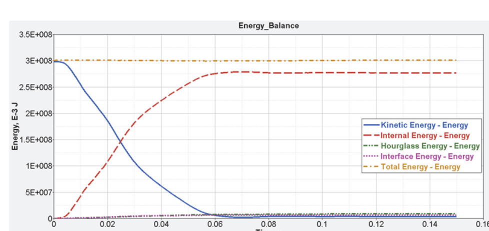

Fig. 40. Case 4 - Front impact - Energy balance

Energy-balance is almost the exact same as the energy path from case 1. The amount of kinetic and internal energy have raised the same which end up to have a higher total energy (Fig. 40).

Case 3 - Side impact

Hence the Automotive Industry Standard (AIS-031) in India specifies the requirements and methods to calculate the strength of superstructure of VANs during and after a crash. At the same time in Europe, the standard “ECE R66” (Economic commission for Europe) is in force to prevent catastrophic consequences of such side accidents thereby ensuring the safety of VAN and coach passengers. We have resided the residual space within the VAN body to determine the safe area for passengers.

Case 3- Boundary conditions

For Side Impact we used trolley with Advanced European Mobile Deformable Barrier face (AE-MDB), accordingly with “Euro NCAP side impact mobile deformable barrier testing protocol” (Fig. 41).

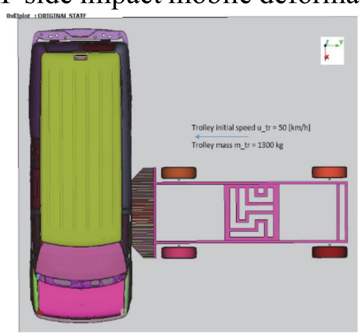

Fig. 41. Side impact - Boundary conditions

Case 3- Results

During a side impact, there is a risk of the driver clamping by the deformable parts of the car. To analyze this risk, we have created the driver's living space (blue block on Fig. 42 and Fig. 43).

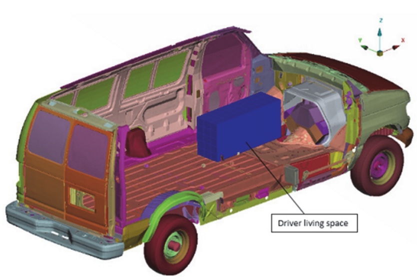

Fig. 42. Initial state- Driver living space location- Some parts of the VEHICLE are hidden

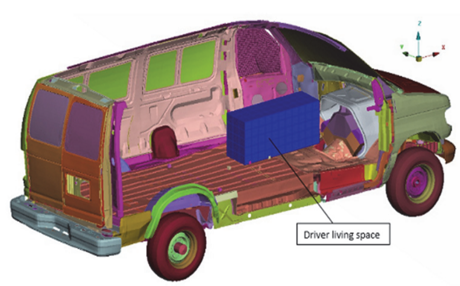

Fig. 43. Side impact- Deformed state- Driver living space location- Some parts of the vehicle are hidden

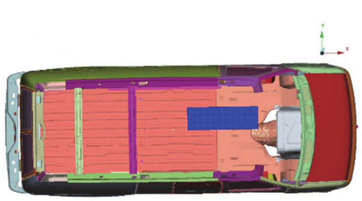

Fig. 44. Initial state -Top view - Some parts of the vehicle are hidden

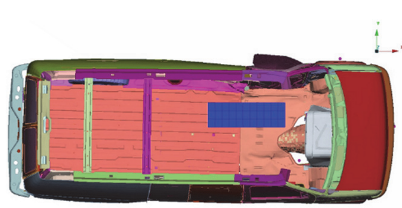

Fig. 45. Side impact- Deformed state- Top view- Some parts of the vehicle are hidden

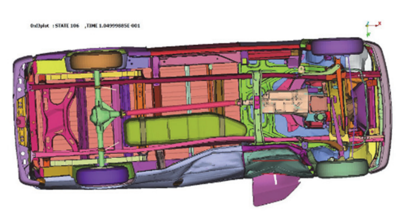

Fig. 46. Side impact- Deformed state- Bottom view- Some parts of the vehicle are hidden

The residual space within the passenger compartment in the structure is unharmed during and after the crash test and that can result to protect the passengers. The residual space which is to be unharmed during the accident of the VAN is shown in Figs. 47-48.

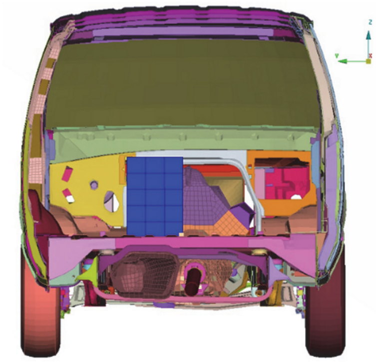

Fig. 47. Side impact- Initial state- Front view- Some parts of the vehicle are hidden

Fig. 48. Side impact- Deformed state- Front view- Some parts of the vehicle are hidden

Fig. 49 shows the location of the inner body beams-sensors from left to right of the driver and passenger area. The displacement is measured to analyze the deformation after the crash test.

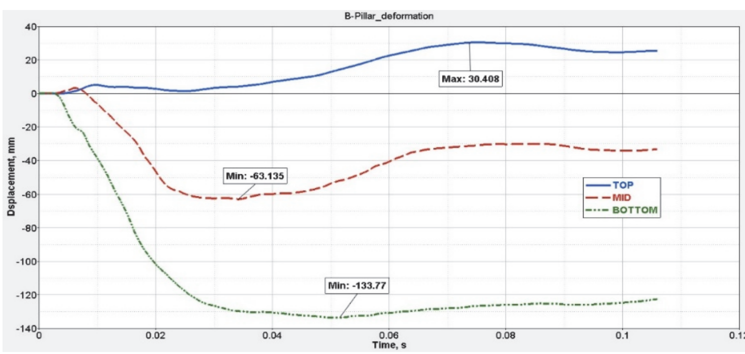

Fig. 49. Inner body beams displacements

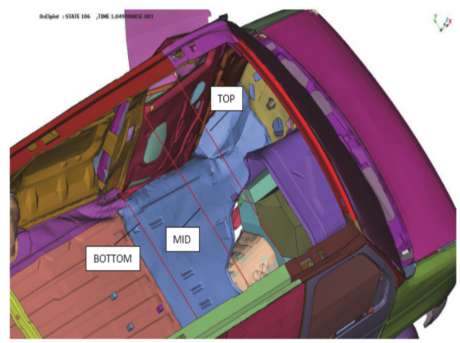

Fig. 50. Inner body beams-sensors location

Fig. 51 illustrates the differences between deformations of inner body beams. The highest deformation would be for the bottom beam as the highest accident pressure and deformation is in the area of bottom and accordingly the lowest is occurring for the top beam sensor.
Three B-Pillar beams-sensors are also located.

Fig. 51. Left door beams velocity

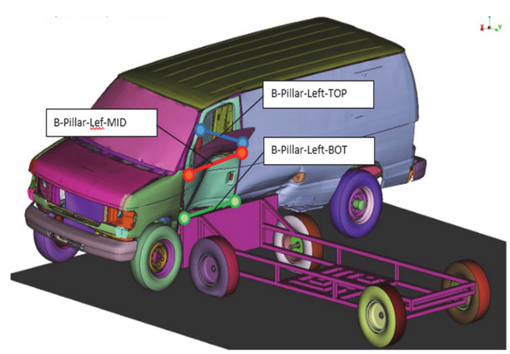

Fig. 52. Left door beams-sensors location

Fig. 52 determines the displacement of the front left door B-Pillar- velocity. As the trolley hits from the left or driver side, it is clear the main damages are in B-Pillar Left-Bottom area.

Fig. 53 shows the Side impact Energy balance graph for the VAN model that will be discussed in case 3. In comparison with case 1, it concludes that there is an increase in energy transfer time. As that can be seen the kinetic and internal energy line crosses to each other, such point on time consideration was recorded. The time was t = 0.057 sec. So, the energy transformation rate from kinetic energy to internal energy affects the energy absorbed in the structure around the bottom B-Pillar beam. Total time for complete energy transformation for the base VAN model was t = 0.12 – 0.057 = 0.063 sec. As the total time to complete energy transmission is higher, it shows the whole body of VAN is stiffer and can absorb more kinetic energy in a longer time. The harm effect into the residual passenger area is less by this pattern.

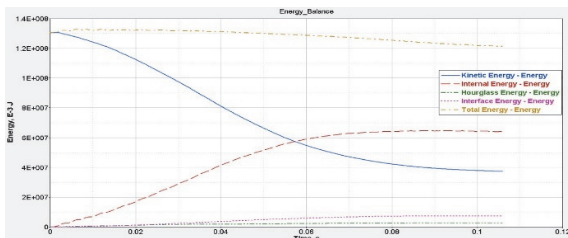

Fig. 53. Case 2- Side impact- Energy balance

Case 4 - Side Impact - Van with 3 cylinders

Case 4 - Boundary conditions

For Side Impact we used trolley with Advanced European Mobile Deformable Barrier face (AE-MDB), accordingly with "Euro NCAP side impact mobile deformable barrier testing protocol" (Figs. 54-55).

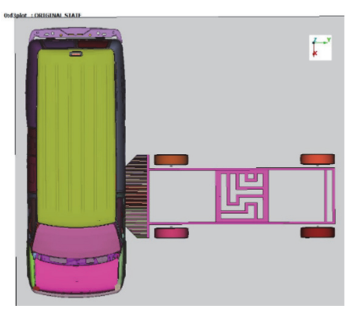

Fig. 54. Side impact - Boundary conditions

Fig. 55. Initial state - Top view - Some parts of the vehicle are hidden

Case 4 - Results

During a side impact, there is a risk of the driver clamping by the deformable parts of the car (Fig. 56). To analyze this risk, we have created the driver's living space (blue block on Fig. 56). Fig. 57 determines the residual drive save space before and after the crash.

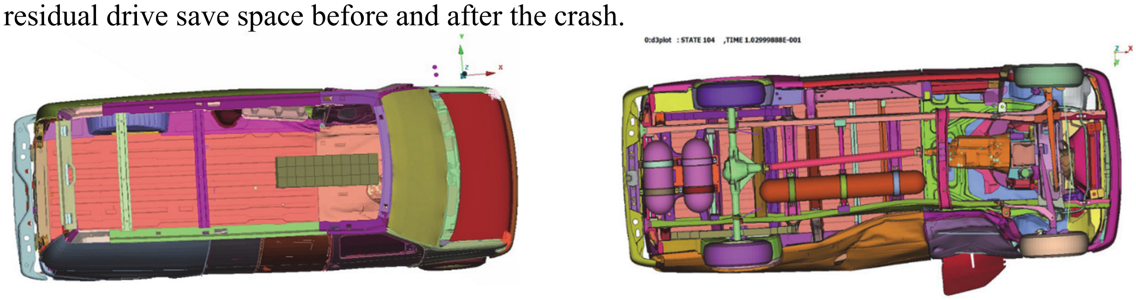

Fig. 56. Side impact - Deformed state - Top view (Left Image)/ Bottom View (Right Image) - Some parts of the VEHICLE are hidden

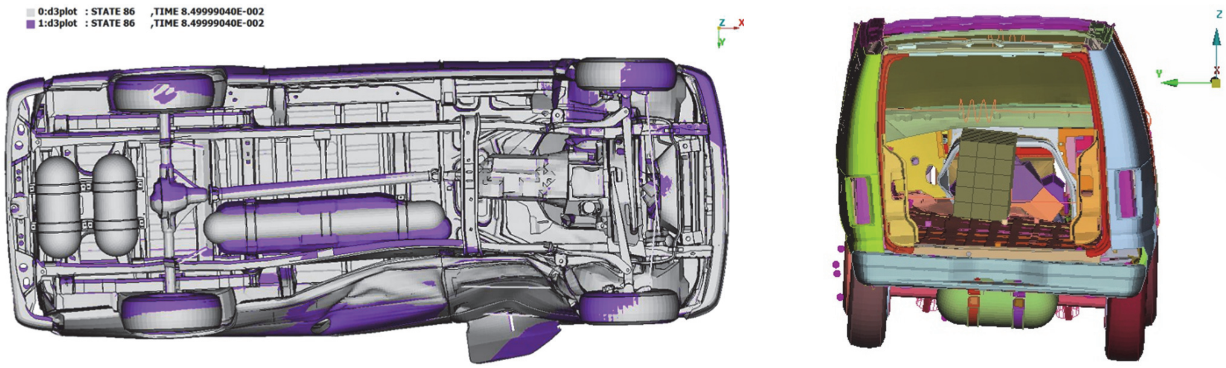

Fig. 57. Side impact - Deformed state - Comparison between Case 1 (Front Impact without cylinders - blue) and Case 4 (Front Impact with cylinders - grey), Left Image/ Rear view (Right Image)

Fig. 58 shows the location of the inner body beams-sensors.

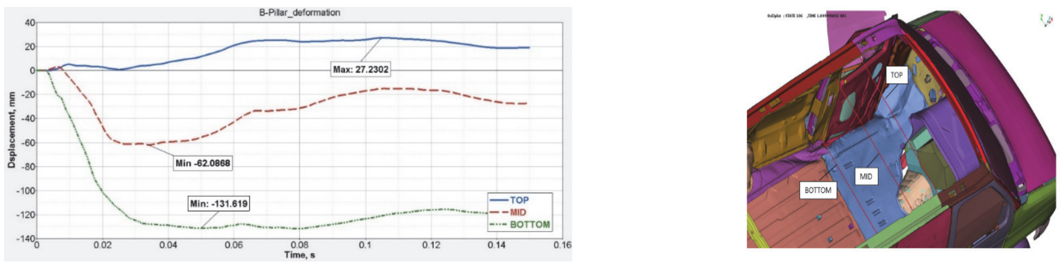

Fig. 58. Inner body beams displacements (left iamge), Inner body beams-sensors location (right Image)

It is wondering once comparing with the same data analysis from case 3, we can see there is an improvement on displacement distances for B-Pillar spots in the top, middle and bottom area. That means the damage area is completely accepted in this case with three CNG cylinders installed in the VAN.

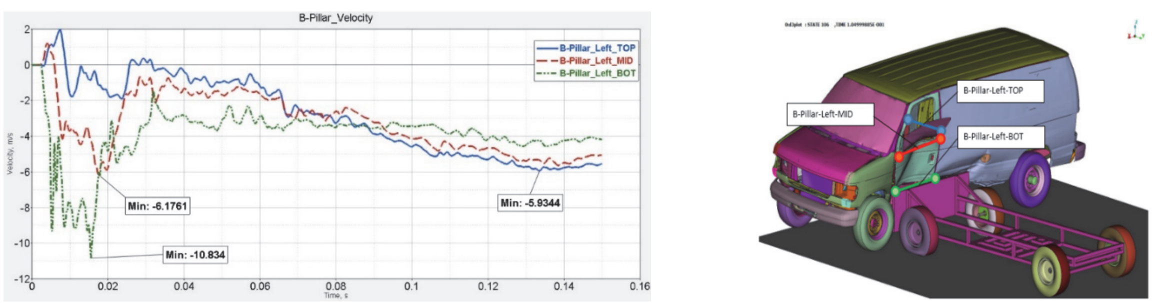

Fig. 59. Left door beams velocity (left image)/ Left door beams-sensors location (right image)

The result of B-Pillar beam velocity is almost the same in case 3 with no CNG cylinder (Fig. 59). The Energy balance is almost the exact same as the Energy path from case 3 (Fig. 60).

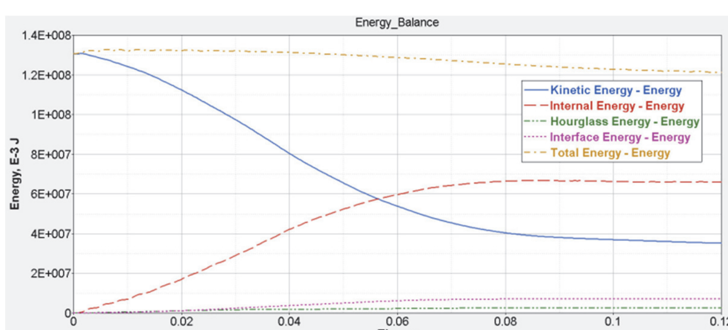

Fig. 60. Case 5 - Side impact - Energy balance

7. Conclusions and recommendations

The simulation crash test result focused on the finite element model of the passenger or school VAN – Ford Econoline and captured the deformation and interaction when three CNG cylinders are installed in the VAN. As it was discussed in section 2, there are several different CNG cylinder locating type methods which each involves a different locating set up which is coming with some advantages and disadvantages. The simulation test focused to stay within the standard safety range for passengers and the CNG cylinders in all crash cases. By analyzing the result of the crash tests, Van safety is the same as when there are no changes done from original vehicle design.

The result elaborates more on front and side impact crash test for the selected passenger or school VAN - Ford Econoline, with three CNG cylinders installed, have enough strength to prevent bending deformation. Energy absorption is adequate, and as the vehicle is within the safety standard boundaries. On the other hand, the location improvement can comprehensively improve the performance of the car with having more fuel storage space.

The first objective of this research was to determine a safe location for CNG cylinders in the VAN. This can be obtained when comparing Energy-Balance graphs in cases 1 and case 2. Both results are kinetic and internal energy crosses each other the same time and the total time to complete energy transmission is equal too. The second objective of this research was to develop an appropriate framework model to locate CNG cylinders in chassis of a passenger VAN with considering safety standards. The data shows that the maximum deformation is less than 4mm, which is almost the same as the displacement result without cylinder installation. The third objective of this research was to determine the crashworthiness characteristics of the VAN body in Euro-NCAP impact safety crash test. The FE model was developed with the crashworthiness which was defined with measuring parameters from Total Energy balance and Inner beam and B-pillar beam sensors location. FE modelling process involved CAD data, pre-processing, meshing, deck preparation, and processor (LS-DYNA). Also, post-processor, displacement plot and energy plot

The last objective of this research was to verify and predict safe seat anthropometry space for crashworthiness safety of CNG VAN passengers. The result of B-pillar deformation and velocity in all cases 2 and 3 confirmed that. On the other side, there is almost no possibility to cross over the residual safe space for passengers after the CNG cylinders are located and mounted in their resided space. Even though we can locate more cylinders inside the VAN body or on the roof, or also on the rear door side of the VAN but, we did not consider these cases in this research.

Crash test simulation (front and side) to understand how passenger safety becomes worse, has it become critical and close to be dangerous. It can be determined during the analysis that the cylinders are the strongest and hardest and heavy parts of the VAN, and based on expert's experiences from the available data, it can be considered in actual real life. Another matter would be the weight of additional and accessories which is an important point regarding the weight of the VAN. Despite adding three cylinders and bracket mounting, the weight needs to be considered as efficient for helping the CNG VAN performance. Therefore, there is no need to add covers around the cylinders as with the recent manufacturing technology and CNG cylinder types, we can use a type of CNG cylinder that can be safe enough during the crash, like type IV. CNG cylinders make the Van heavier and crash test block "penetrates deeper" into the VAN. The VAN body components are softer than the CNG cylinders thus, the main danger is not in the possibility of the cylinder explosion but, probably would be the penetration of the cylinder into the living space of the VAN body. This is one of the main key points that cylinders are not placed close to the passenger's seat inside the vehicle.

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