	Collaborative project Grant agreement: 260087	

WIDE-MOB

Building blocks concepts for efficient and safe
multiuse urban electrical vehicles

Collaborative project

Grant Agreement 266129

SST – Sustainable Surface Transport

Start date of project: 01 December 2010
End date of project: 31 May 2014

Project Coordinator: Luigi Petruccelli

Deliverable D9.13: 42 Months Public report

Author: Luigi Petruccelli

WP8 Leader: CRF

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1. Project description

The WIDE-MOB project aimed at breaking the link between the growth in transport capacity and increased fatalities, congestion and pollution. Transport is responsible for 73% of total oil consumption in EU, it is a major source of pollution and greenhouse gas emissions and the chief sector driving future growth in world oil demand. Most continents have an increasing dependence from primary energy. The demand on increased safety, reduced noxious and green house emissions has the following expectations: less than 30.000 fatalities in EU in the 2010, radical reduction of both CO_2 and NOx aiming at zero local emissions. Transport will be faced to the followings:

- people and good will increase their need of mobility some 35% per decade for at least 3-4 decades
- the number of megalopolis is increasing and most of the traffic will be urban
- urban centers are more and more congested and closed to traffic; 1% of our GDP is wasted in congestion
- mobility is related to invariants such as: people move 1 hour a day
- the average speed, since it has measured the first time in 1923, is stable in the range 35-40km/h
- people tend to relate mobility to a mental freedom and as many as 90% of km are run with a single occupant
- in EU 1 more million cars are on the road every 50 days and globally the number of vehicles is projected to 2200 millions in the 2050.

Mobility is currently based on hydrocarbons, whether from fossil fuels or those combustible from renewable (liquids and gases) sources. Most continents including Europe still have an increasing dependence on primary energy. Moreover, from a European perspective, there is also a comparable relevance on the growing dependence on raw materials, such as aluminum and steel, with accurate market projections and forecasts being severely hampered by global economic instability.

Nevertheless, concerns about the use of primary energy remain dominant, while user expectations also demand increased safety, and reduced noxious and greenhouse emissions. For instance, expectations are for less than 40,000 fatalities in Europe in 2010 with the aim of less than 100 fatalities per million vehicles in 2015.

The market requires at most low cost and environment compatible vehicles.

While architectural requirements, and mechanical and thermal constraints imposed on an electrical powertrain are much less stringent when compared to conventional ICE based vehicles, the needs for cost reduction and range enhancement demand light structures, advanced aerodynamic solutions and optimisation of the drive train as a whole.

WIDE-MOB has addressed the design and development of EV's basic building blocks, including:

• Optimised aerodynamic bodies that radically reduce the drag at any speeds

• Lightweight and low cost bodies designed for high safety under both frontal and lateral crash

• Overall system optimisation based on distributed propulsion including:

  ◦ fail safe distributed propulsion,

  ◦ e-motor and torque control of the wheel,

  ◦ integrated power-energy management and distributed battery packs (high efficiencies over a wide torque/speed range demanded by real-use driving cycles).

• Application of EMC-EMR and low frequency electromagnetic field (EMF) design concepts based on "prudent avoidance practices" for field mitigation on occupants. The high currents and voltages produced in electric drive trains pose new problems in terms of EMF which may become a health risk to occupants

• Modular and reconfigurable design addressing the WIDEst needs with ergonomic on board.

2. Project objectives

The main objective of the project has been to develop building block concepts that could be widely applied to most architectures for the manufacturing of efficient and safe EVs.

The radical reduction of energy consumption, use of raw materials, CO_2 and noxious emissions are addressed by:

• low weight architectures,

• distributed electrical drive trains based on high efficiency permanent magnet motors with integrated magnetic gear,

• combined use of batteries for maximum energy recovery during braking,

• extremely low aerodynamic drag characteristic,

• solar energy harvesting.

Safety is addressed by:

• EMF design concepts based on "prudent avoidance practices" for field mitigation on occupants,

• position of both driver and occupants along the central axis of the vehicle for maximum stability in low radius curves,

• safety cell optimised for both lateral and frontal crashes,

• fail-safe schemes based on:

  ◦ Inherently fault-tolerant (failure in one drive will not significantly affect the vehicle performance),

  ◦ Fail-safe such that no spin or complete loss of power will take place,

  ◦ Freedom in distribution of traction torque according to weight shift (further improvement in traction efficiency),

  ◦ Improved traction control on low friction road and safety enhancement.

3. Vehicle scenario

The WIDE-MOB vehicle has been conceived to meet the regulation of the heavy Quadricycle world L7e and with minor addition of systems the much more engaging regulations of the conventional M1 vehicles. The standards and codes most relevant to the WIDE-MOB project are evolving as new technologies are introduced and developed.
The weakness and the ambiguities of the current EU regulation No 168/2013 of 15 January 2013 on safety demand a revision aiming at assuring a much higher safety ranking for these categories of vehicles representing the fastest growing sector of electro-mobility.
Electro-mobility is not just cars: a classification of the forms of mobility per their total mass and energy consume is necessary to better evaluate market's demand in relation to technology evolution and cost. The rationale is that we cannot use the same criteria when comparing e-bikes, quadricycles, electric Smart (956kg), Renault ZOE (1468kg), Nissan Leaf (1521kg), Opel Ampera (1732kg), Tesla Model S (2018kg).

Type	Light EVs (e-Bike)	LightE VS (other)	Micro e-Cars light-heavy Q-cycles	City e-Cars NEDC	Small e-Cars NEDC	Mid size e-Cars NEDC	Large e-Cars NEDC
Weight kg	15-50	50-350	350-700	700 -1100	1100-1350	1350-1600	1600-2000
Energy kWh/100km	1-2	2-4	4-8	9-12	12-15	15-18	18-25
kg/100km of Li-ion b.pack (180Wh/kg)	6 -11	11-17	23-50	50-67	67-85	85-100	100 -150
DC link (V)	24-48	48-65	48-98	65-240	120-360	240-480	360-480++
Nominal Power (kW)	0.05-1.0	to 3	to 15	10-40	18-70	50-140	70-200+
Speed km/h	to 35	to 45	45-90+	By design			
	No driving licence/14years/16years/ No heavy safety restrictions			M1 passenger cars: ABS,EPS…mandatory. NCAP 5 almost a must.			

Fig.1: *Wide Mob can be made to cover either the EU regulation No 168/2013 of 15 January 2013. L…..L7e as well as the Regulations of the M1 world.*

The classification should not be regarded as sharp as it could appear from table. Clearly vehicles cannot be classified by weight only, their footprint and shape influence consume as well. LEVs as well as micro EVs are very heterogeneous and could be subdivided into several subclasses. In some cases cars of 800-900kg are classified as small while the category of large e-cars (ACEA executive) could be subdivided in two. The average weight of US passenger cars is 480kg higher than the average weight of the EU ones and a car that in the US is by most considered a micro car in Europe is classified within the lower-medium segment.

The macro classification per mass is the most useful to understand how technology evolution impacts performance and production costs. Weight is usually correlated to size and aero drag influencing consume, range and total capacity of the battery pack.

Besides weight influences:

- The DC link Voltage and the complexity of the battery system,
- The rated power then heat dissipation in power electronic and motor(s) and the overall cooling system,
- Semiconductor technology to be used (MOSFET/IGBT). Silicon is the basic material for LEVs, Micro, City and Small EVs while mid-size and large e-cars benefit of GaN, SiC components capable of handling much higher currents with better efficiency and heat dissipation property.

The global production of LEVs is approaching 50 millions units/year and in a logic of a step per step implementation Micro cars and quad-cycles (here all together called Micro EVs) are stimulating the interests of new producers and investors.

According to Regulation (EU) no 168 of 15 January 2013 "on the approval and market surveillance of two - or three-wheels vehicles and quad-cycles", heavy quad-cycles can be produced with a mass in running order ≤600 kg (vehicles intended for carrying goods not including the mass of batteries), and maximum net engine power up to 15 kW. Including the battery pack the total weight of these vehicles could be > 700kg. The Mob platform discussed in this paper is positioned in between the two quite different sectors of Micro EVs and M1 City e-cars. The registration of a Micro EV can be made meeting few regulations and fast to implement processes, but in this paper we demonstrate that with the addition of minimal hardware they can meet as well the burden of the regulations necessary to enter the M1 world thus eliminating the restrictions on their use.

4. Structural design

The design development of the vehicle has been based on safety and ergonomics criteria at the lowest weight. Within the project a novel solution of fully autonomous and self-standing axles based on a parallelogram suspension has been developed aiming at taking full advantage of electric propulsion.

Referring first to the more classical McPherson architecture, to assure easy entry for both the driver and rear passengers we adopted a two door opening on the same side incorporating the B-pillar into the front door. Below figure shows the analysis performed to assure driver's visibility according to the existing regulations-directives and a picture of the first prototyped developed with on-board a driver and a passenger.

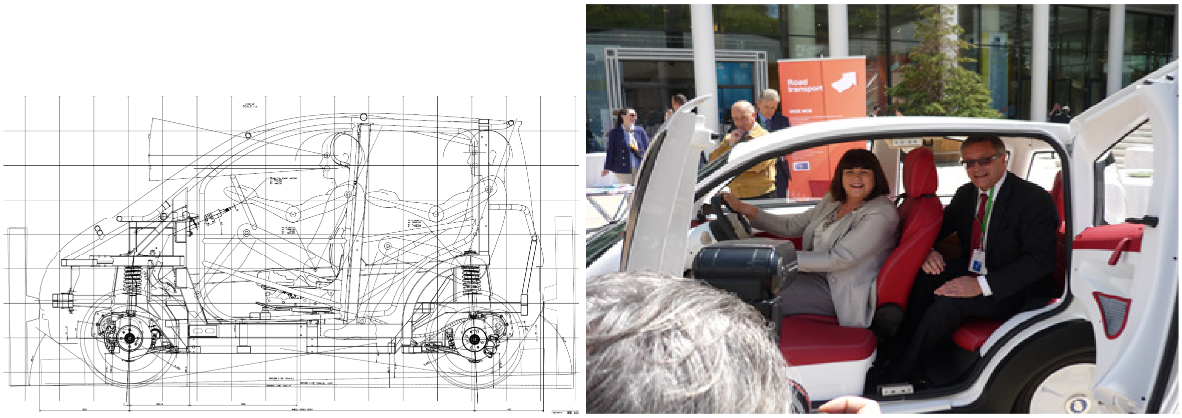


Fig.2: *Interior design for ergonomy and occupants on vehicle*

For the upper and lower body structures (floor side walls, reinforcements, fenders, pillars and cross car beams) we have designed and implemented two solutions aiming at:
1) Very large scale and low cost production based on "conventional" sheet metal forming,
2) Tubular frame with the addition of few parts only made by sheet metal forming conceived for low and medium-low production volumes to reduce the invested capital. In the next picture the design developed based on the tubolar frame and the two produced rolling chassis.

Fig.3: *Structural design and two prototypes realisation*

4.1. Virtual crash analysis

The simulations have been performed for the following regulations:

- Frontal Impact ECE-R12
- Frontal impact ECE-R94
- Side Impact Barrier ECE-R95 left side.

FRONT CRASH ECE-R12

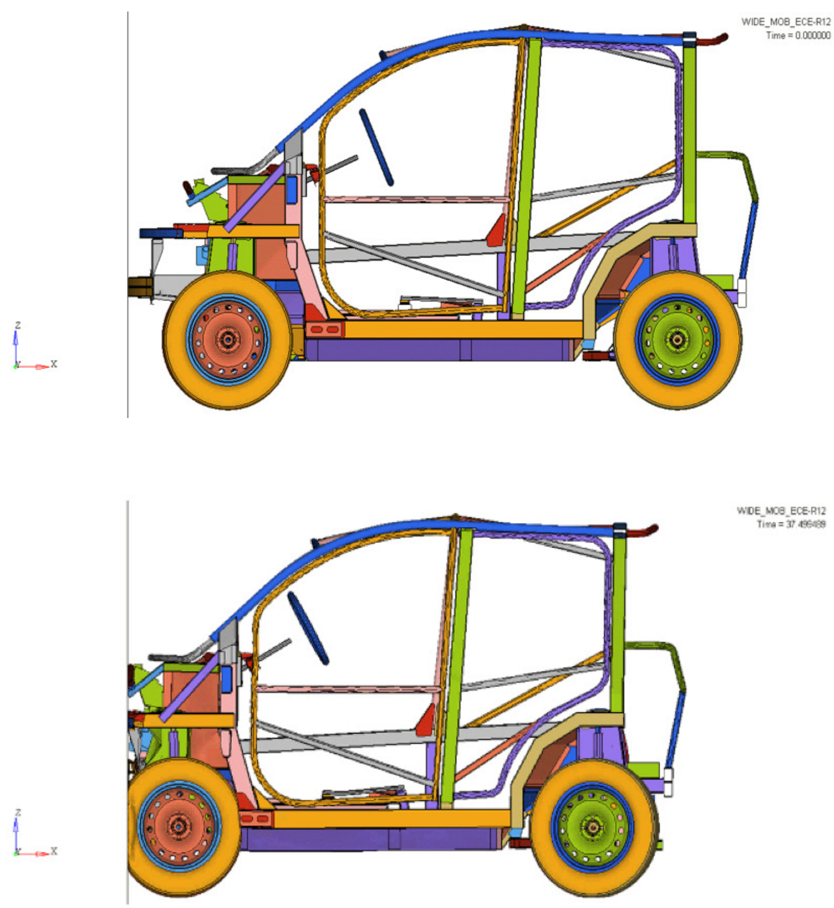


Fig.4: Before and after FRONT CRASH ECE-R12: Side view

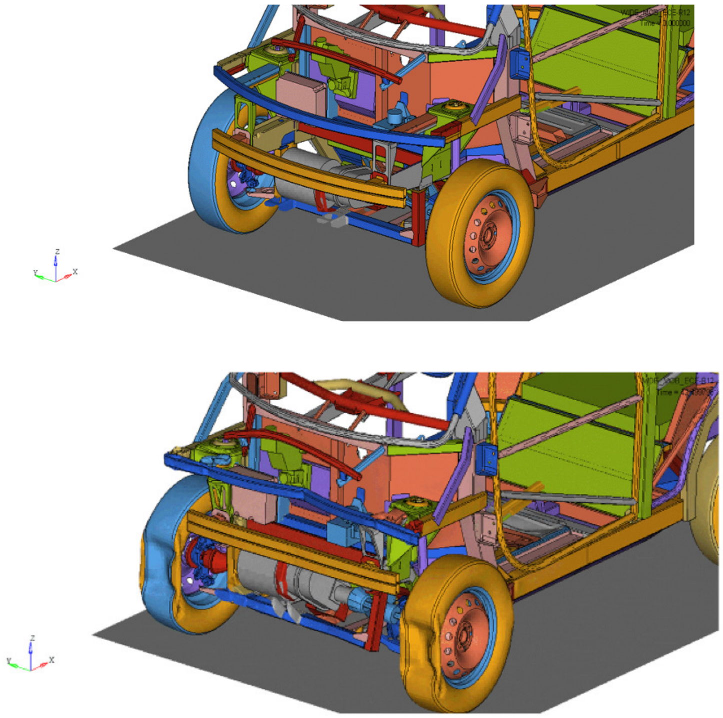


Fig.5: *Before and after FRONT CRASH   ECE-R12: Front view*

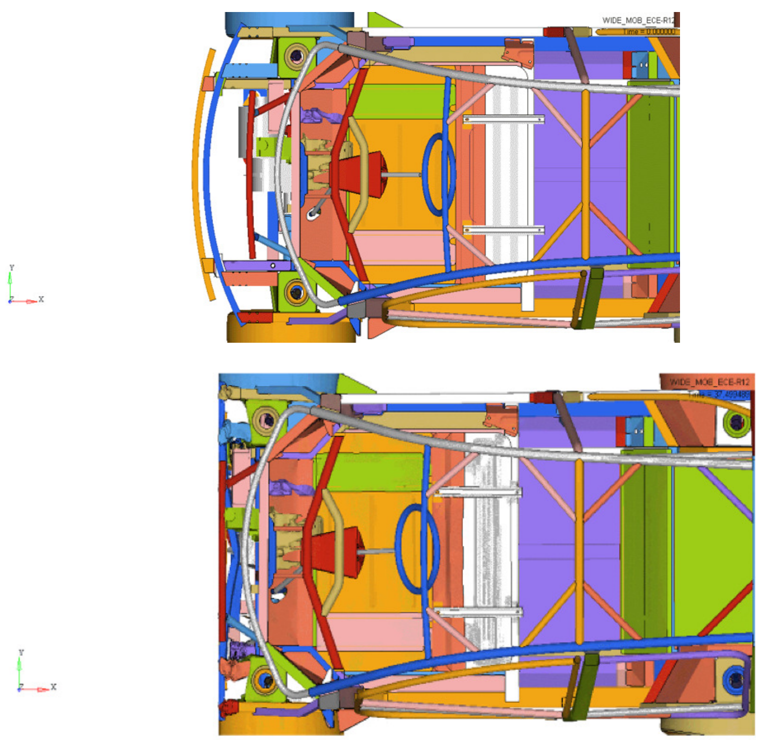


Fig. 6: *Before and after FRONT CRASH   ECE-R12: Top view*

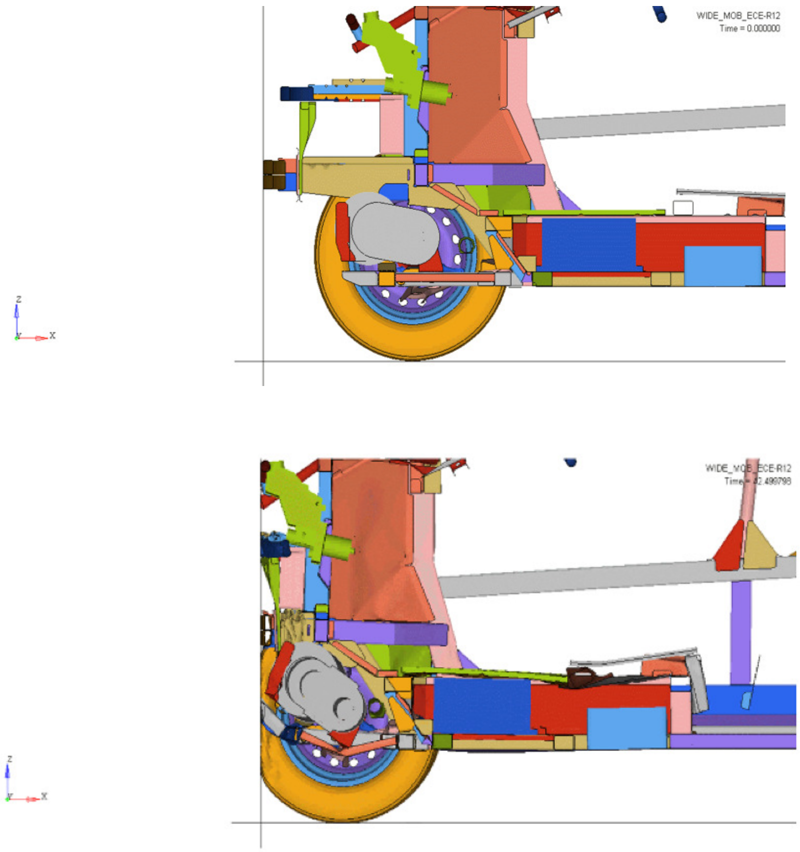


Fig. 7: *Before and after FRONT CRASH   ECE-R12: Detail Side view*

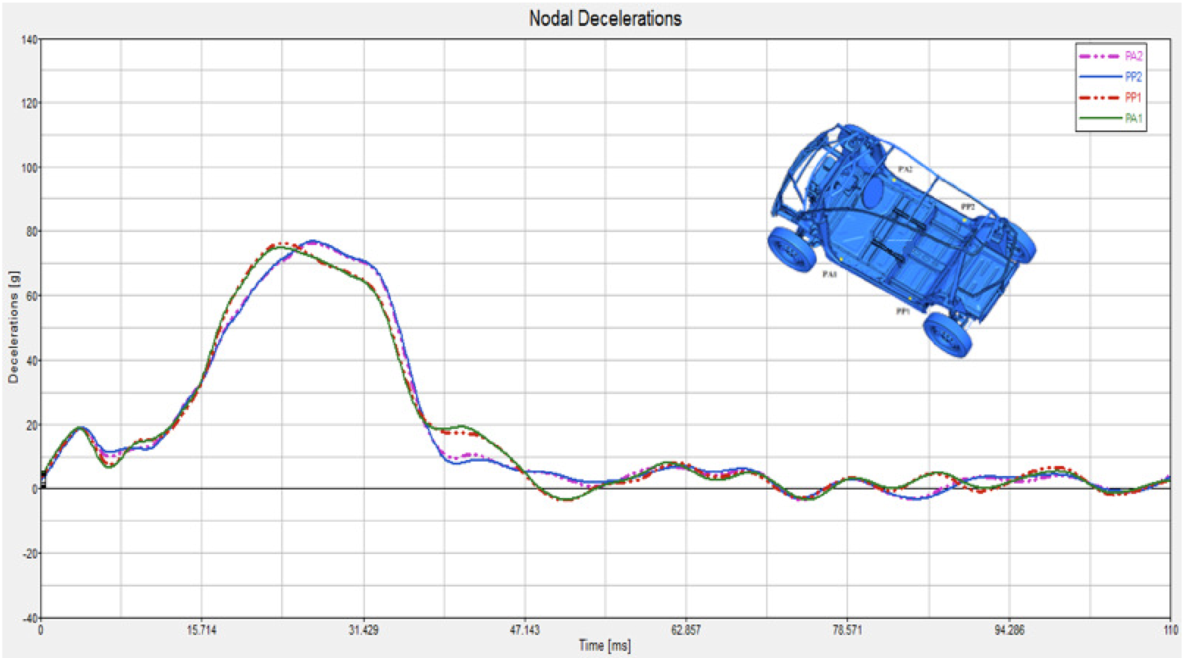


Fig. 8: *FRONT CRASH ECE-R12* *Decelerations [g] SAE 60 FILTER*

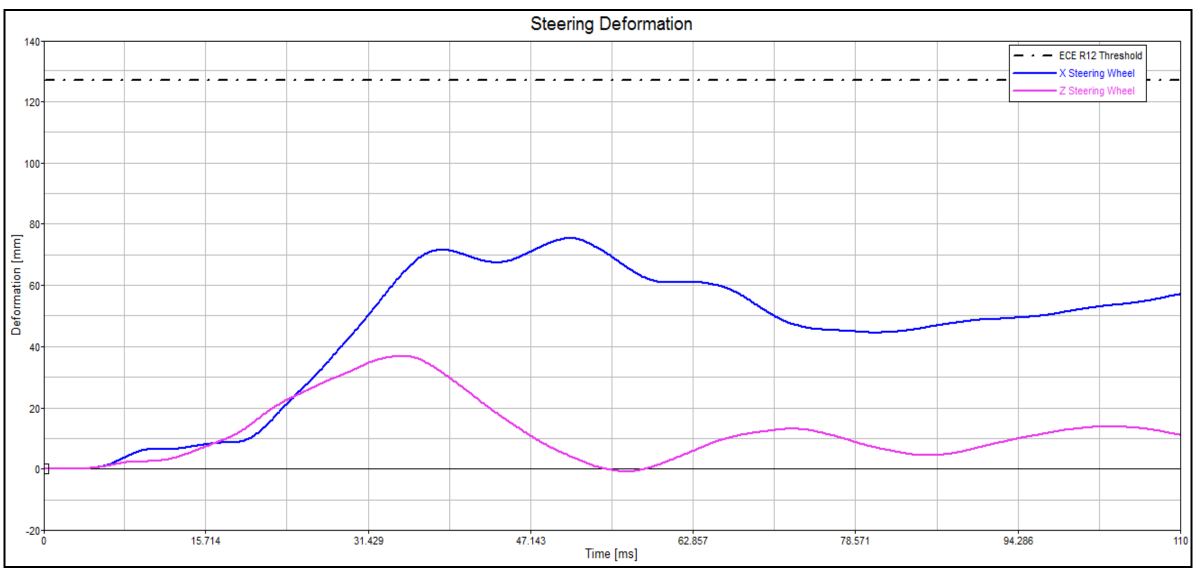


Fig. 9: *FRONT CRASH ECE-R12* *Steering Displacements [mm]*

ECE R-94

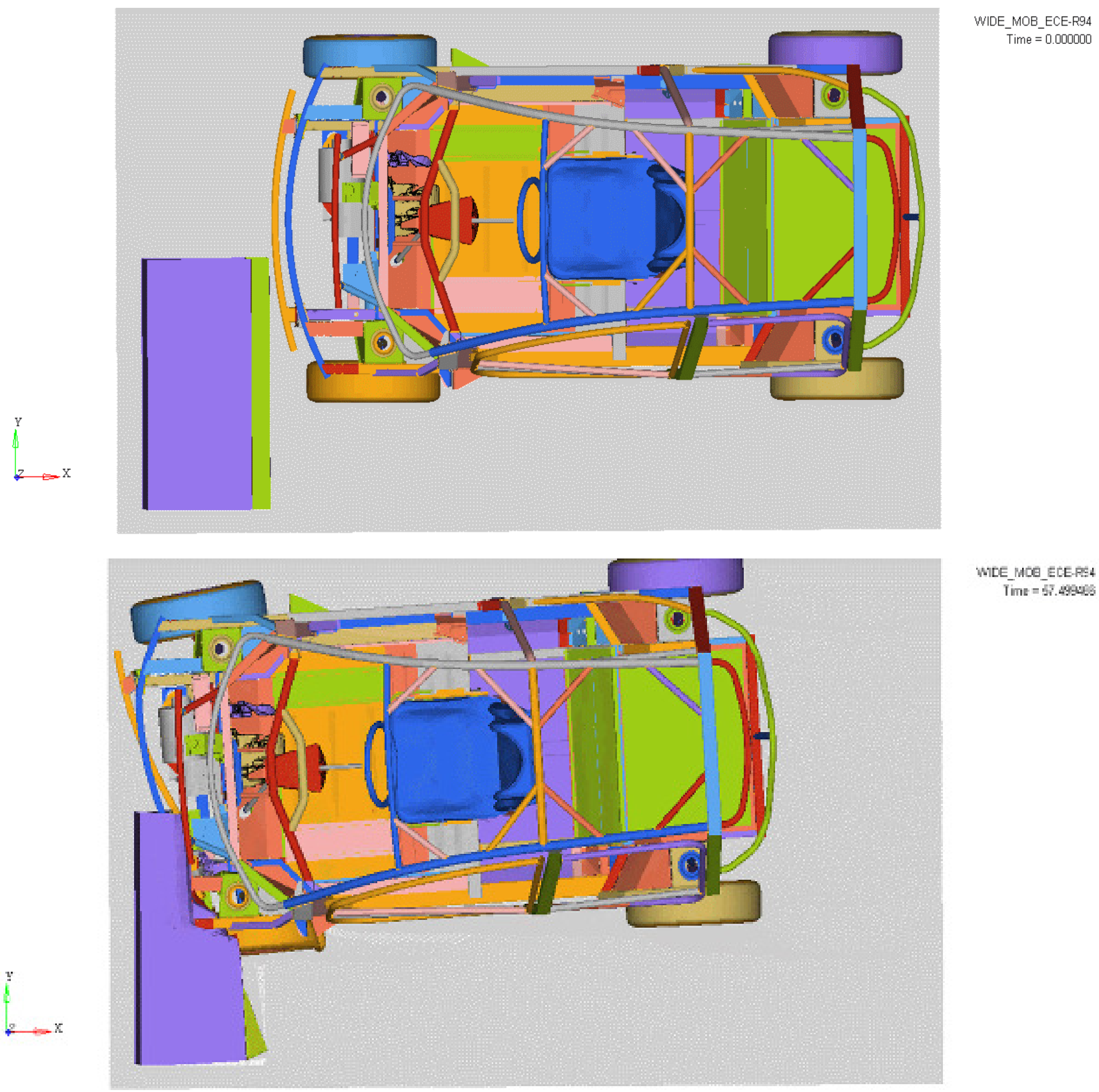


Fig.10: *Before and after crash ECE-R94: Top view*

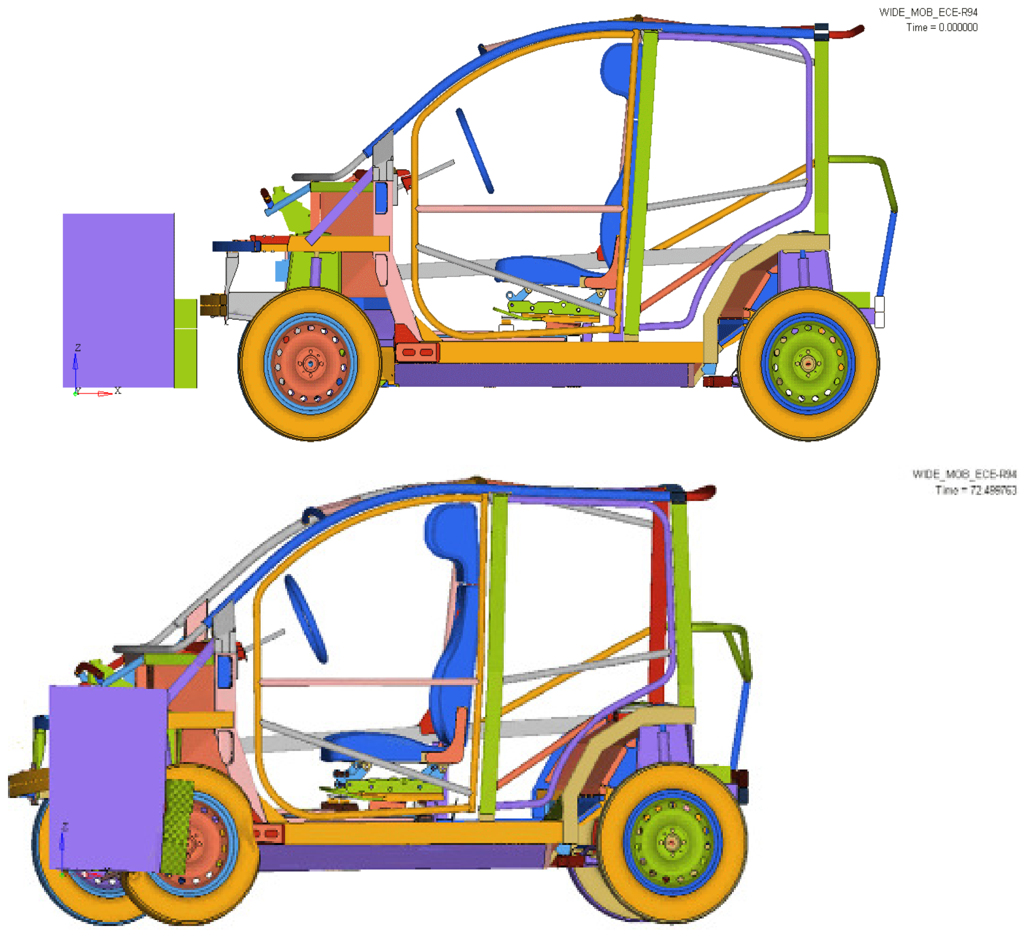
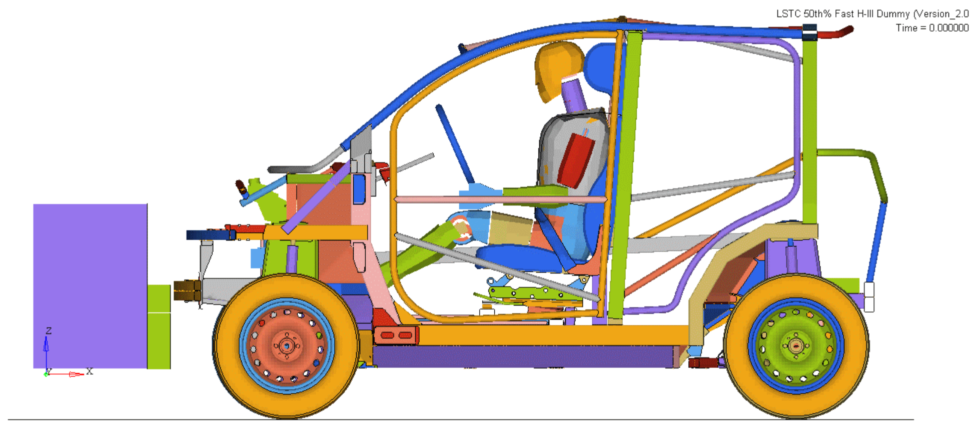


Fig. 11: *Before and after crash ECE-R94: Side view*

ECE-R94: With Dummy



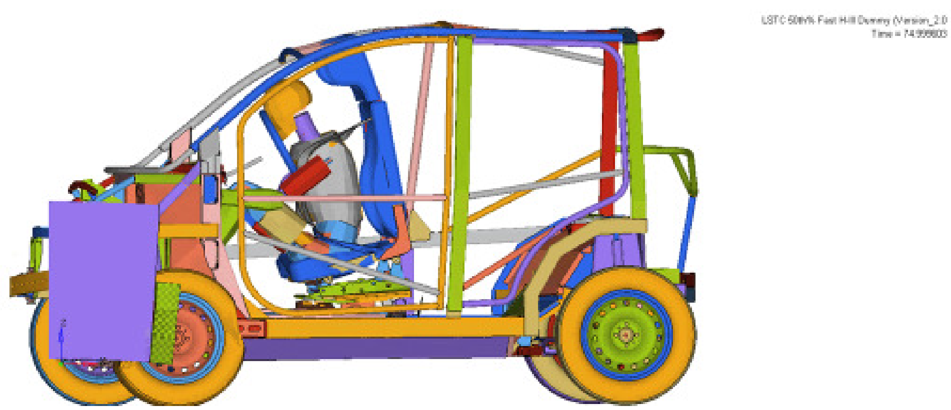


Fig. 12: *Before and after crash ECE-R94 with Dummy: Side view*

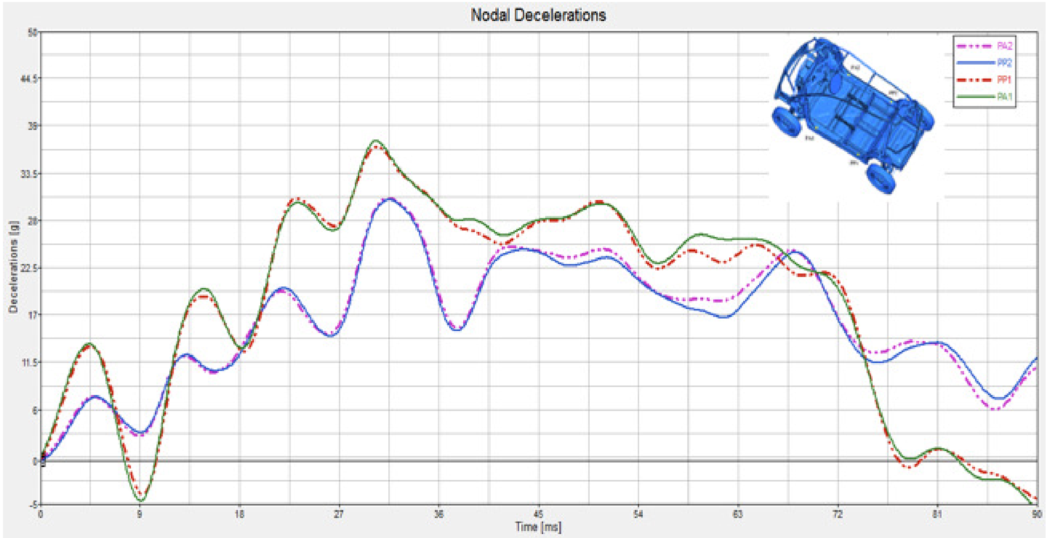


Fig. 13: *ECE-R94:* *Decelerations [g] SAE 60 FILTER*

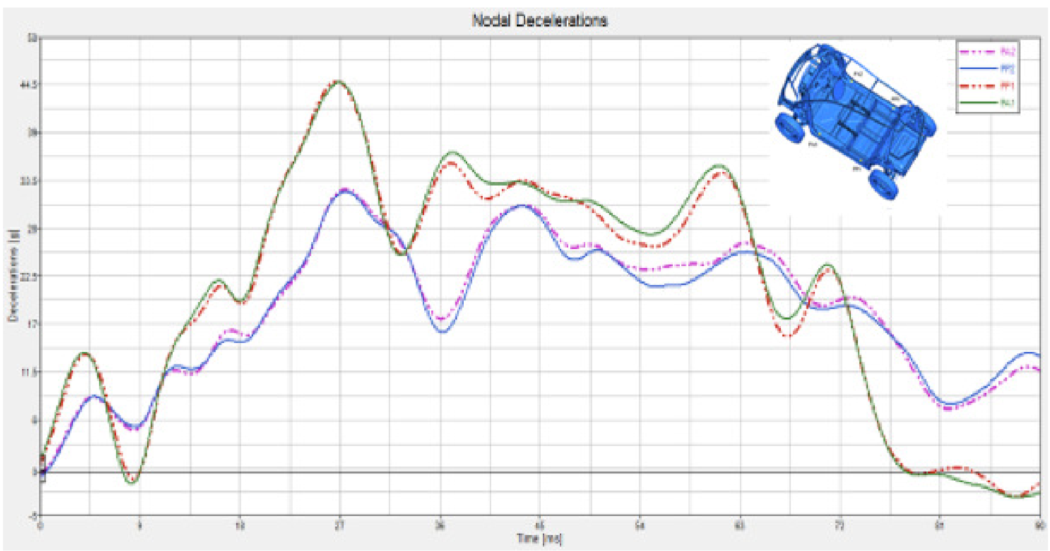


Fig. 14: *EUCAP SAE 60 Filter – SPEED 64 Km/h*

Lateral Crash ECE-R95

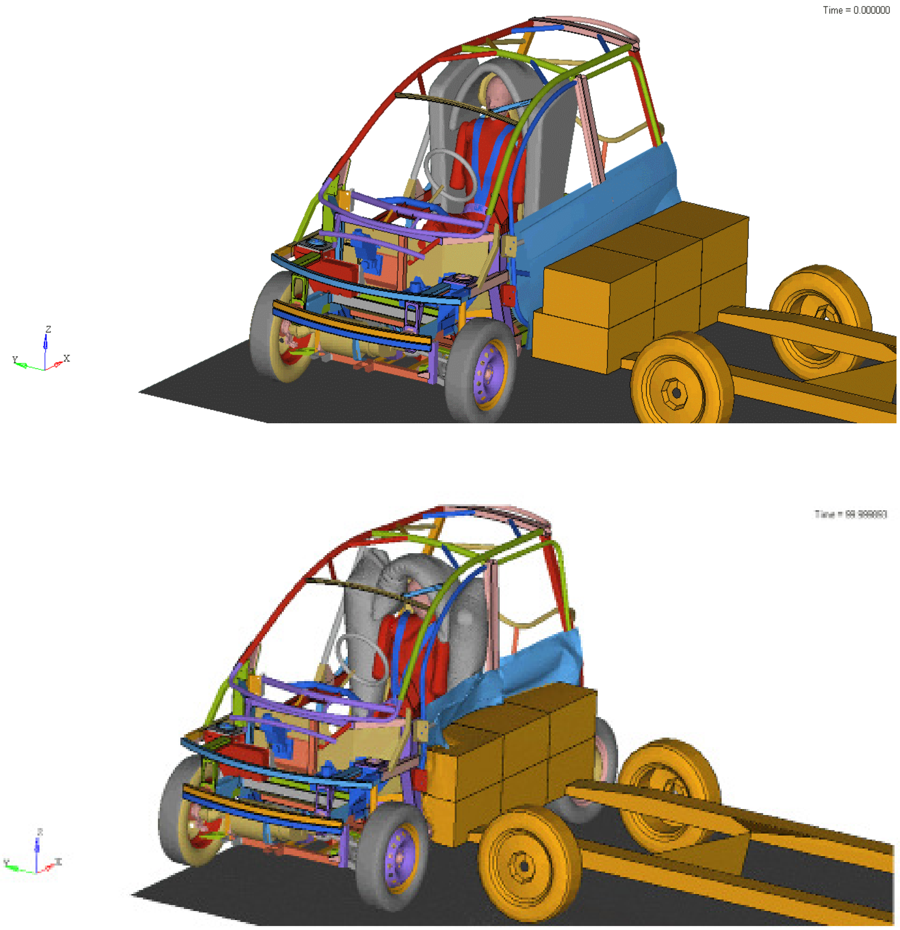


Fig. 15: *Lateral Crash ECE-R95 side view*

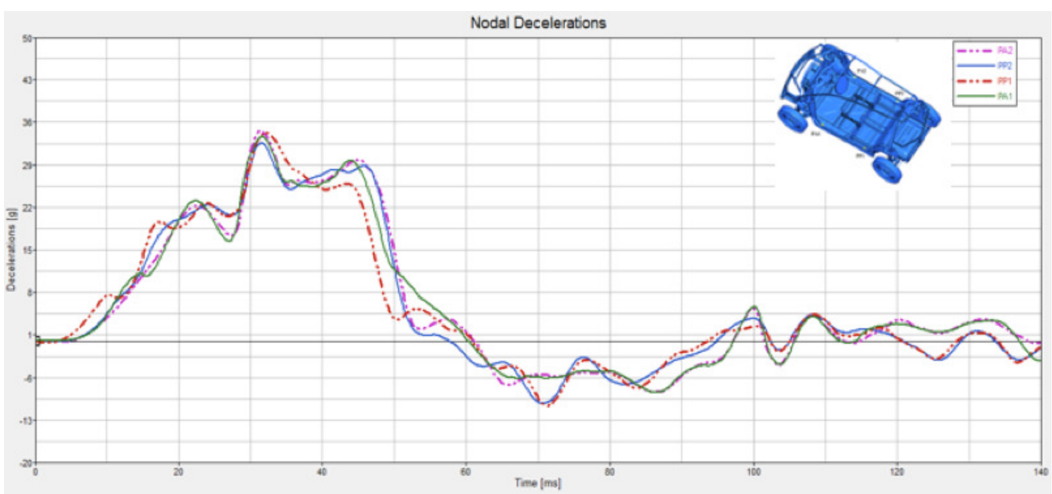


Fig. 16: *ECE-R95: Decelerations SAE 60 FILTER*

4.2. Physical crash tests - Front crash: ECE-R12

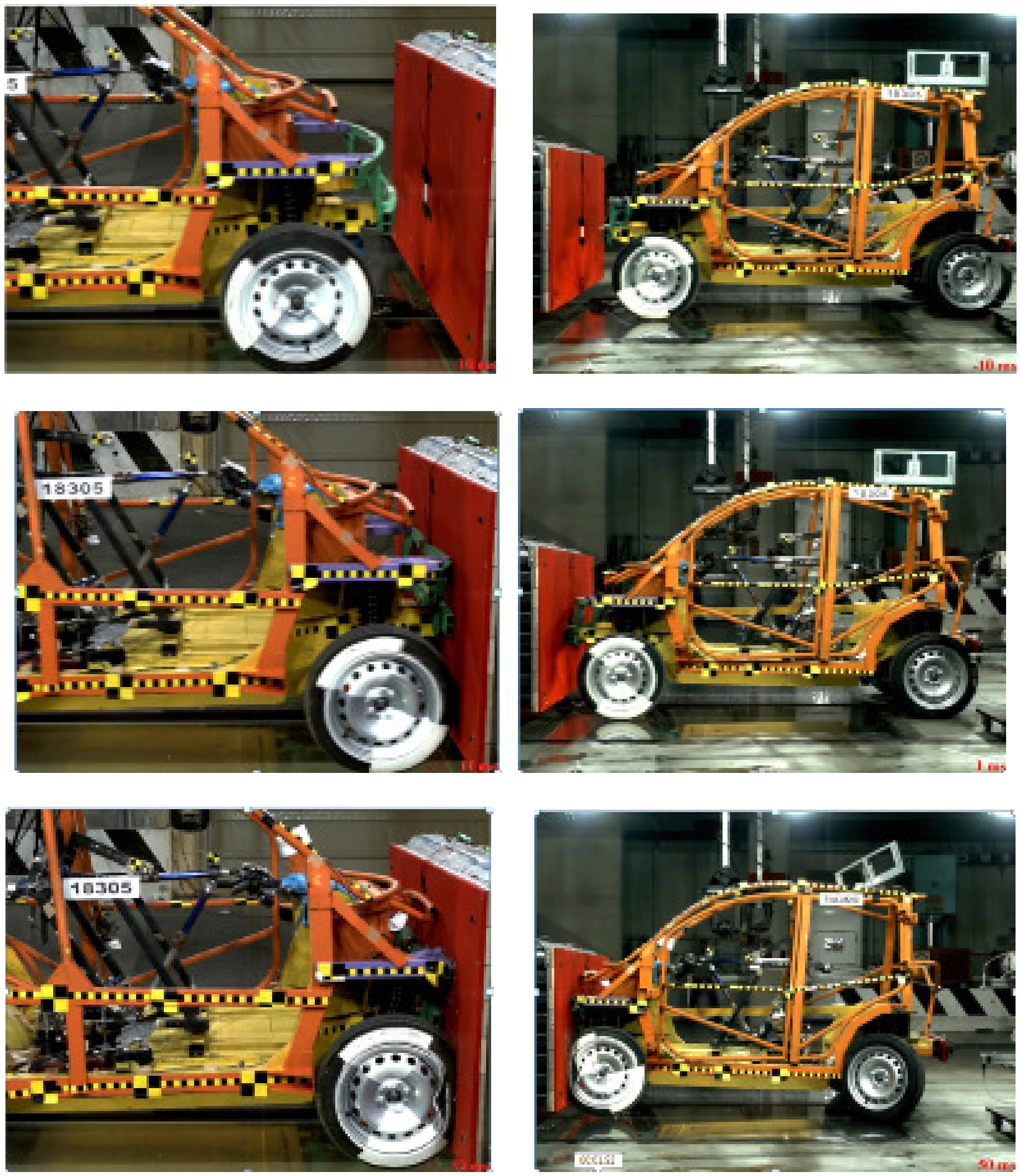


Fig. 17: *Physical crash test sequences*

Fig. 18: *Physical crash test different views*

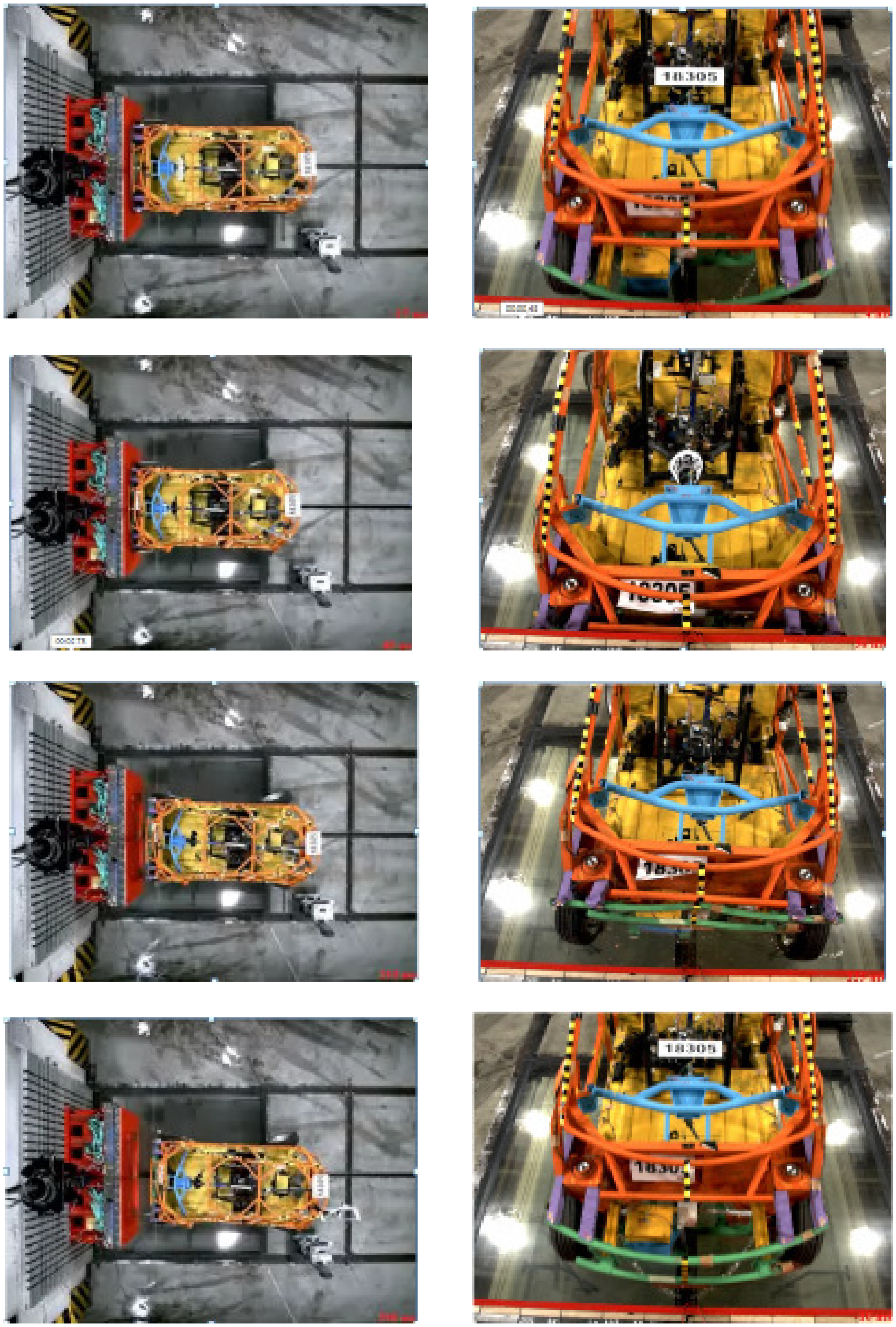


Fig. 19: *Physical crash test sequences in top and front view*

4.3. Interpretation of the results and conclusion

The iterations applied on the geometry of the overall structure, type of chosen materials and thicknesses of the parts have led to acceptable deformations and accelerations against the three most important tests ECE-R12 frontal steering wheel, ECE-R94 frontal 40% off axis, ECE-R95 side impact.
The physical crash test applied according to ECE-R12 confirms the simulations.
A specific report with the measured deformations after the physical crash test is attached to this deliverable:

- Energy is well absorbed by the front crash box,
- The measured deformations of pillar A and on the most important points of the structure are all acceptable,
- ECE-R12; the measured horizontal **(5.3cm)** and vertical displacements **(3.5cm)** of the steering wheel is then less than half of the requirement (the top of the steering column and its shaft shall not move backwards, horizontally and parallel to the longitudinal axis of the vehicle, by more than 12.7 cm and also not more than 12.7 cm vertically upwards, both dimensions considered in relation to a point of the vehicle not affected by the impact).
- ECE-R12 the measured peak accelerations on the nodal points are of the order of 60g, that is, 12g lower than the value defined by EURO NCAP for L7e higher performance limit of the head with airbag and 2g lower than the higher performance limit without airbag (note: the proposed L7e EuroEURO NCAP test considers a deformable barrier while the barrier of the ECE-R12 is rigid, that is, ECE-R12 is more severe than the new 2014 EuroEURO NCAP test).
- ECE-R95 (simulations only): no severe intrusion with peak accelerations limited to below 50g.

The physical crash test confirms as well the weak points of the design and specifically:

- the deformations of the rear wheels are not acceptable, the fixing points of the lower arm of the rear suspensions need to be made more robust;
- the front seat used in WIDE MOB is fixed on a transversal linear bench and because of that it is elevated from the floor; simulations and physical crash tests confirm the importance to couple the front seat and the linear bench with robust fixing points.

In summary within the project we have proved that the structure of Micro EVs weighting less than 600kg before the battery, when properly equipped with airbags and safety belts, can meet the UN-ECE regulations in place and be potentially awarded the highest Euro NCAP ratings.

5. Electrical safety

The collaboration of the WIDE-MOB project with the EM-safety project has led to the setting of basic design criteria for the powertrain that can be synthetized in the following points:

Batteries

- Since a battery pack consists of either or both a parallel and serial connection of sub-modules, currents in the sub-modules and in the interconnectors may become a significant source for EMF emission. The battery compartment and the passenger seat area should always be separated by a bilayer steel-plastic shield.
- The cables connecting battery cells and submodules should not form a loop, and where possible, the interconnectors for the positive polarity should be as close as possible to those of the negative polarity.

Cables

- To minimize EMF emission DC cable carrying significant amount of current, should preferably be made in the form of a twisted pair so that the currents in the pair always flow in the opposite directions.
- For three-phase AC cables, three wires should be twisted and made as close as possible so as to minimise its EMF emission.
- All power cables should be located at least 100mm away from metallic parts of the lower and higher chassis structure,
- All power cables should be positioned as far away as possible from the passenger seat area, their layout should not form a loop and some forms of shielding is always preferred,
- A thin layer of ferromagnetic shield is recommended as this is cost-effective solution for the reduction of EMF emission as well EMI emission,
- Where possible, power cables should be separated from the passenger seat area by a steel sheet.

Motors

- Where possible, the motor rotation axis should not point to the seat region.
- Motors and passenger seat area should be separated by a steel sheet.
- Motor housing should be electrically well connected to the vehicle metallic chassis to minimise any electrical potential.
- Drive and motor should be mounted as close as possible to each other to minimise the cable length.

6. Prototype developed in the project

Following picture shows the prototype developed.

Fig. 20: *Front view of display, steering wheel and engine selector*

Fig. 21: *Seat block*

Fig. 22: *Driver and passenger on Wide-Mob vehicle*

Fig. 23: *Driver seat including four points belts and airbags (front view). A second C-shape configuration for the lateral airbags has also been studied and patented to contribute to protect the rear passengers (*BIT17333 TO2014A000258**)**.

Fig. 24: *Demo of front seat airbag system protection*

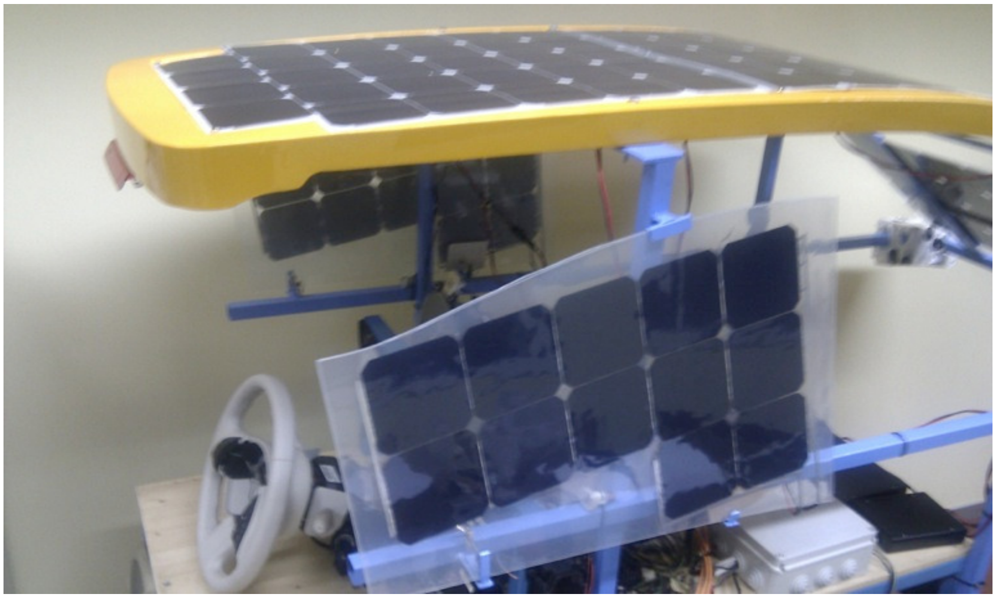


Fig. 25: *PV panels at Lab bench test*

Fig. 26: *PV roof at TRA2014*

7. Conclusions

When the project started at the beginning of 2011 the micro EVs world was new and very little background material was available because neither the old EU regulation nor the new 168/2013 on L7e demand crash tests or homologations applying the UN-ECE or Euro NCAP ratings adopted for M1 vehicles.
During the almost four years of the project, WIDE-MOB phase generated knowledge and solutions demonstrating that vehicles weighting less than 600kg before the battery can:

- Comply with the most stringent safety regulations applied for M1 vehicles on redundancy (fail safe), vehicle control stability, frontal and lateral collisions,
- Be designed with performance (range, speed, acceleration and fun to drive) that can satisfy most people needs in terms of passenger vehicles, delivery of goods or leisure-sports,
- Be equipped with smart solar panels that can harvest energy sufficient to avoid charging many days of the year in most EU southern countries.

The positive and successful experience of WIDE-MOB, in terms of novel knowledge and patents generated, established the base for a European platform for the development of micro electrical vehicles including standardization related aspects to make electrical mobility safer and more efficient.

8. Public Poster

Two posters were prepared at the end of the project to show the outcomes of the activities to the TRA2014 attendees in Paris.
These two posters, one for Exhibition area and one for Poster Session of TRA2014 submitted papers are shown in the following pages.

SEVENTH FRAMEWORK PROGRAMME

DG - RTD

WIDE - MOB

Efficient and safe multiuse urban electrical vehicles

Starting Date: 1st December 2010
Ending Date: 30th April 2014

Partnership: Centro Ricerche Fiat (I), IFP Energies nouvelles (F), ST Microelectronics (I), Polimodel (I), The University of Sheffield (UK), Warsaw University of Technology (PL)

Motivation and Objectives

- Safety cell optimised for both lateral and frontal crashes
- Multimotor powertrain architecture
- Energy recovery during braking
- Low aerodynamic drag
- Solar energy harvesting

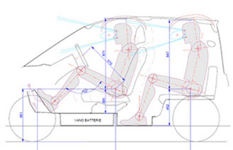
Main deliverables

Prototype of safe and efficient vehicle conceived for a typical urban and sub-urban mission to demonstrate the applicability of the developed technology advances.

WIDE- MOB Concept
Lenth: 2900 mm
Width: 1470 mm
Height: 1520 mm
Front track: 1340 mm
Rear track: 1240 mm
Wheelbase: 2010 mm
Frontal area: 1.8 sqm
Weight: 680 kg w/o batteries (85 kg)
E-motor: 2x5 kW
Battery capacity: 10 kWh
Range: 150 km
Max speed: 90 km/h (120 km/h possible)
Tires: 145/65 R15

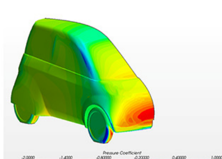
Guidelines to develop electric passengers cars, IPR and knowledge/experience upon which to build a world-leading EU position to exploit the global uptake of green mobility.

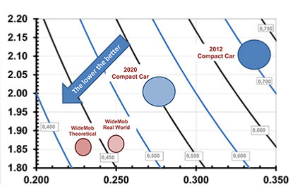
Ergonomics



Aerodynamic

The optimised shape allows low aerodynamic drag and good ergonomics Key dimensions: wheelbase: 2010 mm, front track: 1340 mm, rear track: 1240 mm, frontal area: 1.8 sqm.

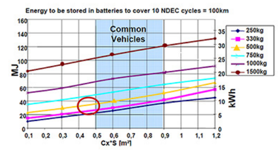


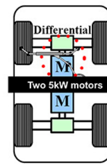


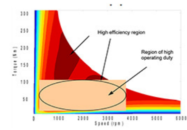
30% lower drag than vehicles of comparable size

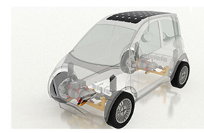
For further information: http://eeepro.shef.ac.uk/wide-mob/

Efficient two motor powertrain

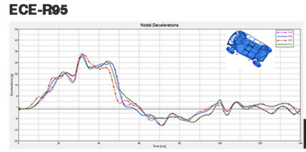




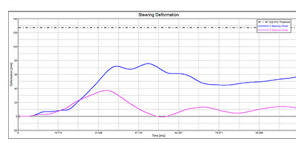


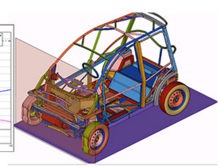


ECE-R95

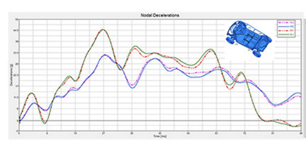


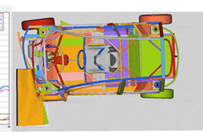
ECE-R12: Steering Displacement





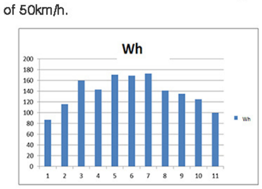
ECE-R94: SAE 60 Filter – SPEED 64 Km/h





On-board "Smart" Photovoltaic

Measurements confirm that the vehicle can run the targeted 20km a day at a constant speed of 50km/h.



Power comsumption with full weight 800kg

Constant speed
50km/h: 48.37 Wh/km
100km/h: 107.30 Wh/km

NEDC
No energy recovery: 80 Wh/km
Energy recovery 100%: 70 Wh/km

1600/75=21km/day NEDC cycle

TRA 5th conference
Transport Solutions: from Research to Deployment
Innovate Mobility, Mobilise Innovation!
Paris - La Défense CNIT, 14 - 17 April 2014

The European MOB design platform for both Micro EVs and small M1 Vehicles

Pietro Perlo, IFEVS, Italy
Pietro Guerrieri, POLIMODEL, Italy
Carloandrea Malvicino, L.uigi Petruccelli, Andrea Pipino,
Silvano Sandri, Vincenzo Di Lago, Centro Ricerche Fiat, Italy
Gregory Font, IFP Energies Nouvelles, France
Antonio Lionetto, ST Microelectronics, Italy

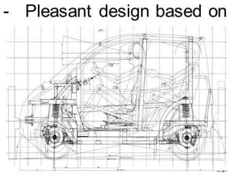
Introduction

Electric vehicles are set to play a key role in the future of urban mobility, reducing pollution, decreasing dependence on fossil fuels and saving drivers money. The demand for mobility is increasing in Europe as elsewhere: several studies show that, mainly because of immigration from less developed countries; the linear trend of EU traffic growth is expected to continue beyond 2020. Because the road network of several EU Member States is at the limit of its capacity, rather than a growth of conventional vehicles sales, needs and limitations will demand the integration different modalities and vehicles having a lower carbon footprint. Rather than forms of mobility of ever increasing prices, there is a growing rational demand for: clean, safe and low energy consumption vehicles, requiring less energy to be produced, and using recyclable materials-systems.

Specifications

The basic requirements set for the MOB platform are:

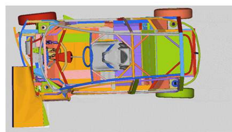
- Micro EV type (<600Kg before batteries) with minimal functionalities but capable to be update to the M1 class,
- Low footprint allowing facilitated parking,
  < 1500 mm width, < 3000 mm length,
- Low aero-dynamic drag,
- General performance: max speed +120km/h, slope > 30%, acceleration 0 – 50km/h <4.3s,
- Drive train addressing redundancy and high efficiency,
- Air cooled power electronic and motors,
- Simplified and easy to update electrical architecture; i) partition by independent functional blocks; ii) off-board charger, iii) application of partial battery swapping concepts, IV) remote control and management by portable devices,
- Application of Electromagnetic Reliability (EMR), Electromagnetic Compatibility (EMC) and Electromagnetic Field (EMF) design concepts based on "prudent avoidance practices" for field mitigation on occupants,
- Integrated photovoltaic panels with adaptive electronic for a continuous optimization of the output under shadow,
- High efficiency auxiliaries with LED and IR heating,
- Lightweight and low cost chassis designed on the base of an asymmetrical safety cell assuring high safety to meet the Euro NCAP tests rating,
- Ergonomic on-board space, facilitated entry on both front and rear sides with three ergonomic seats,
- Easy to reconfigure architecture to satisfy a wide range of missions, max volume when carrying goods,
- Pleasant design based on simplicity and essentials.

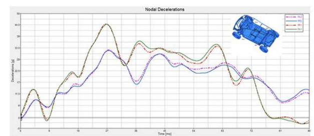


Ergonomic study

Hybrid Tubular/Sheet metal structure

Results





Simulated crash tests prove that the adopted structures can meet ECE-R94 (frontal collision safety), ECE-R95 (lateral collisions) and ECE-R12 (steering impact in frontal collision).

Smart photovoltaic system with1.9m^2 of effective working area and 20.5% efficiency has demonstrated that an average 20km/day run by solar radiation only is feasible.

WIDE vehicle typologies to address most market needs

Conclusions

The micro EVs world is new and very little background material is available because neither the old EU regulation nor the new 168/2013 on L7e demand crash tests or homologations applying the UN-ECE or Euro NCAP adopted for M1 vehicles. The MOB platform has generated knowledge and solutions demonstrating that vehicles weighting less than 600kg before the battery can:

- Comply with the most stringent safety regulations applied for M1 vehicles on redundancy (fail safe), vehicle control stability, frontal and lateral collisions,
- Be designed with performance (range, speed, acceleration and fun to drive) that can satisfy most people needs in terms of passenger vehicles, delivery of goods or leisure-sports,
- Be equipped with smart solar panels that can harvest energy sufficient to avoid charging many days of the year in most EU southern countries.

With that the MOB platform is setting EU commercial standards in quality, safety and performance against which non-EU manufacturers have to be faced in the next years.

Main references

1. M. Grunig et al, An overview of Electric Vehicles on the market and in development, Report, Delft April 2011.
2. http://www.evworld.com/news.cfm?newsid=30732

* Contact : pietro.perlo@ifevs.com

9. Project Consortium

WIDE-MOB Consortium is composed by 6 Partners from 4 Countries (Italy, France, UK and Poland).

More information including a video could be found at the following web address:

http://eeepro.shef.ac.uk/wide-mob/