GVTR: A GENERIC VEHICLE TEST RIG REPRESENTATIVE OF THE CONTEMPORARY EUROPEAN VEHICLE FLEET

Florian Feist, Nisha Sharma, Corina Klug
Graz University of Technology
Austria

Franz Roth
Audi AG
Germany

Stefan Schinke, Alexander Besch
Volkswagen AG
Germany

Florian Dornbusch
Bertrandt AG
Germany

ABSTRACT

In the ACEA funded project ProPose a generic vehicle model was developed: (1) It was specifically developed for replicating the leg-loads in pedestrian accidents. (2) It is representative of the contemporary European sedans meeting FlexPLI requirements. (3) It is available in numerical and experimental environment. (4) It is intended for investigating the performance of aPLI, for validating numerical models of advanced legform impactors like aPLI and for the comparison of kinematics and responses of different HBM lower limbs. The structural impact response of vehicle front ends was captured with impactors: A rigid cylinder was equipped with 20 contact force transducers along its axis. The impactor’s motion was prescribed, such that an intrusion of (up to) 120mm was consistently achieved. Tests were conducted at four levels along the vehicle height (spoiler through bonnet leading edge) and at six positions along the lateral axis of the vehicle. The contact forces of individual force transducers were assigned to the four contact regions (spoiler, bumper, grill and bonnet leading edge). Impactor tests were conducted against nine sedans, eight SUVs and three sportscars. For each vehicle category median force-penetration characteristics were established. The geometry of the CoHerent models was adopted (and cross-checked against the median reference lines established in the study ProPose).

In the numerical environment the GVTR was tested in impacts with full human body models, an isolated leg with an upper body mass and a beta-release of aPLI. In the experimental environment the GVTR was tested with aPLI and FlexPLI. Body loads in GVTR-vs-HBM and a selected vehicle-vs-HBM match very well. The same applies when comparing full HBM and isolated leg loads.

The study included vehicles provided by German, Czech and French manufacturers. The GVTR’s structure and geometry is very simplistic for the sake of repeatability, robustness, testing costs and avoidance of error sources in the numerical model of GVTR.

MOTIVATION

In current pedestrian protection testing a flexible pedestrian legform impactor (FlexPLI) is applied, which has a significantly higher biofidelity compared to the EEVC pedestrian legform impactor [1]. Still, both (FlexPLI and EEVC WG17 legform) consider the lower limb only. Such FlexPLI fails in robustly replicating the bending loads in all vehicles (low and high bumper vehicles), particularly in the femur, due to the lack of the upper body [1,2]. In order to further improve the biofidelity of flexible legform impactors, in various attempts an upper body mass was added, eventually leading to impactors like aPLI, which development was largely based on the extensive numerical studies with Human Body models (HBM).

Generally, research and development in the area of pedestrian protection largely relies on numerical simulation methods. Such not only representations of the human body (through HBM), or anthropometric test devices (like aPLI) in numerical codes are needed, but also of the vehicle. Ideally, a vehicle model for the development of new pedestrian impactors shall replicate the shape and the structural behaviour of the contemporary vehicle fleet, while not being just the numerical representation of a specific vehicle-make or -model. While providing realistic structural response upon impact loading, the vehicle model should be very simple (almost over-simplistic) in terms of number of materials used, boundary conditions and contact interactions.
INTRODUCTION

The project ProPose is funded by ACEA, the European Automobile Manufacturers’ Association. The first phase of the project ProPose investigated injuries to the upper femur and pelvis using the ‘Generic Parameterisable Vehicle’ (GPV), that was established in LS-Dyna for that purpose [3]. GPV allows to distinguish between the injury risk induced by the structural impact response and the vehicle shape. In the second phase of ProPose also injuries to the lower leg were considered. To close the gap between the numerical and experimental world, a generic vehicle test rig (GVTR) was required, allowing a side-by-side comparison of the purely numerical human body models (HBM) and anthropometric test devices (ATD).

This paper summarizes the development of GVTR v0 and v1, as well as the application of v0 in testing of FlexPLI and aPLI. The GVTR shall provide an optimal framework for validation of ATDs. Hence there are a number of requirements, that arise. The GVTR shall
- provide good repeatability and reproducibility,
- provide realistic and representative structural response upon impact,
- rely on well validated and generally available material models,
- be robust against fabrication and manufacturing tolerances,
- provide simple and time-efficient test-setup,
- provide separated load-paths, not influencing the others,
- be suitable for oblique testing,
- be representative in terms of shape of the contemporary European vehicle fleet.

METHOD

In the following sub-chapters the methods for the creation of GVTRv0 and v1 are summarized: (1) establishing the shape, (2) establishing the structural impact response and (3) designing and manufacturing – each seperated for GVTR v0 and v1.

Establishing the Shape

GVTR v0

GVTRv0’s shape is based on the mid-section contour of the generic CoHerent family car, which was developed for EuroNCAP [4]. The interrelations between GPV, GV, GVTRv0 and GVTRv1 are outlined in the chapter ‘Discussion’.

The outer contour of 19 contemporary and frequently sold vehicles (market introduction: 2009-2015) were provided by ACEA members, covering four vehicle categories. Only vehicles that were categorized as Sedan (n=6) were considered for GVTR v0. The mid-section contour of each vehicle was approximated with eight bezier-curve segments, each governed through six parameters (due to tangency conditions, the total number of parameter reduces to 29). Then the median of each parameter was established, leading to the CoHerent GV sedan mid-section contour [4]. For the GVTR v0, though, the centreline contour was approximated through four straight lines, by connecting SP1 with BP1 and BP2 with BP3 to form spoiler and bumper, respectively (Figure 1). For BLE a 120mm plane was placed centrally on BL1 at an angle of 50° relative to the horizontal. GRL connects the bumper’s upper edge with the BLE leading edge.

Figure 1: CoHerent GV mid-section curve (exemplary depiction of the approach – shape is made up)

GVTR v1

ACEA members provided the reference lines (spoiler, bumper and BLE reference lines) of 20 Flex-PLI compliant vehicles, covering three vehicle categories: sedan, SUV and sportscar. Further, the OEMs provided ground offsets, i.e. an z-offset which is common for the respective vehicle model. Reference lines were discretized in 50mm steps (y-coordinate). Z-coordinates were offset with the provided ground offset. The x-coordinates were adjusted such that the most forward point (of SPL or BMP reference line) is zero. Then for each discrete y-position (0, 50, 100, …) the median x- and z-coordinate were established. Doing so the median
reference lines for each vehicle category were established. Figure 2 shows the median reference lines in red – and the individual lines in light grey.

GVTR v1’s shape was established in the following way:

- BLE segment: A 120mm line placed centrally on the mid-section BLE point and inclined by 50° relative to the vertical. The 120mm are based on the assumption, that the area lying 60mm ahead and behind (measured along a tangent to the BLE-point) are considered the contact area ‘BLE’. At the same time this distance covers 6 of the 20 contact force transducers on the impactor (see sub-chapter ‘Establishing the Structural Impact Response’).

- GRL segment: An oblique line going from the uppermost BMP point to the leading BLE point, leaving a gap of 25mm to the BMP and BLE segment. The 25mm distance between the panels are considered sufficient to prevent any trapping of the ATD.

- BMP segment: Based on impactor testing (described later), the height above ground of the maximum force at an intrusion of 80mm was established for each vehicle. Then the median height of these maximum force levels was established, resulting in a height of 465mm above ground. For the BMP segment a vertical line was placed centrally on that point (x=0, z=465). The length of the line is adjusted such that the GRL segment goes through the mid-section bumper reference line (leading to a BMP line length of 145mm, a SPL line length of 145mm and a GRL line length of 120mm)

- SPL segment: A vertical line going from mid-section SPL point to a point lying 25mm below the lowermost BMP line. Again the 25mm are based on the consideration, that trapping of ATD parts between the deformed panels shall be prevented.

Just like in GVTRv0, the origin of the vehicle coordinate system is such that the x-y-plane coincides with the ground. The x-axis is pointing forward, the y-axis to the left and the origin of the x-axis coincides with the vehicles leading point.

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Establishing the Structural Impact Response

GVTR v0

The force-penetration corridors for GVTRv0’s are based on the corridors established in the EuroNCAP funded project CoHerent [4]: A rigid cylindrical impactor (length=400 mm, radius= 60 mm, mass= 6 kg) was propelled at 11.1 m/s (i.e. 370 Joule) against the spoiler, the bumper, the bonnet leading edge and the bonnet of the 19 sample vehicles. The tests were conducted to the vehicle’s centreline and to a lateral offset position. The simulations were run until the impactor returned to the initial position in the unloading phase. The contact force and the impactor-displacement were used to derive force-deflection curves for each impact location.

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The number of vehicles per category was limited. Therefore it was decided [5] that the median, maximum and minimum force-deflection characteristics are established based on all vehicles in the study. This seemed feasible
(see Figure 4) since median curves showed comparable behaviour and differences within a category were found higher than differences between the categories.

**Figure 4: Median force-deflection characteristics at bumper centreline, for different vehicle categories [5]**

**GVTR v1**
A rigid impactor with the same dimensions as in GVTRv0 was used. The following modifications were introduced:
- The impactor’s motion was prescribed such to gain a consistent intrusion of 120mm.
- The impactor’s face was covered with 20 force transducer, to distinguish between contact forces generated by the respective contact area or by the adjacent contact area.
- A horizontal spoiler test was introduced.
- The bonnet impact test was dismissed.
- The vehicle was tested at the centre line and at five lateral offset-positions.
- Vehicle sample was reduced to Flex-PLI compliant vehicles. Further the category ‘MPV’ was dismissed.

Test Areas or impact points along z-axis (height) were established in the following way – see Figure 5):
- Spoiler impact, horizontal (SPH): Upper edge of impactor aligns with horizontal line 100mm above spoiler reference line (SPR). The SPR is established just like the LBR but with a 45° contact line
- Spoiler impact, oblique (SPV): Impactor centre is aligned with SPR
- Bumper impact, horizontal (BMP): Impactor centre is aligned with a point 50mm below upper bumper reference line (UBR)
- Bonnet leading edge impact, oblique (BLE): Impactor centre is aligned with BLE

Tests at each z-location are conducted six times, i.e. at centerline, and five offset positions. The two outer impact points are tested at 15 and 30 deg (angle between displacement vector and vehicle’s x-z-plane) – see Figure 5.

**Figure 5: Impactor Testing – GVTR v1 (SPH, SPV, BMP and BLE Test) (Picture of Vehicle: EuroNCAP)**

The impactor may contact multiple contact areas at a time. To distinguish the effect of adjacent contact areas on the overall contact force, the contact between impactor and vehicle is established through multiple sub-contacts.
Contact forces per contact areas are summarized by adding the sub-contact forces. I.e. Contact forces established between impactor and grill in the BLE test are assigned to the contact interface “grill” – see Figure 7. The contact force established over the entire length of cylindrical impactor is denoted as e.g. “BLE all” (=green, orange and magenta in Figure 7). The contact force that can be attributed to the BLE only (=orange) is denoted as ‘BLE only’.

Figure 7: Impactor Testing – GVTR v1 (contact force transducers) – example BLE test (Picture of Vehicle: EuroNCAP)

For each impact area (SPH, SPV, BMP, BLE) and lateral impact location (Loc #1 through #6) 10, 50 and 90 quantile curves were calculated based on the test curves of each vehicle (after offsetting and discretizing the abscissa values at 1mm stepwidth) – see Figure 8. These loading and unloading curves were established for sedan, SUV and sportscar. Further it was distinguished between ‘only’ (contact force associated with a specific contact area) and ‘all’ (total contact force, possibly including the contributions of adjacent contact areas).

Figure 8: Example for loading curves established in the oblique spoiler impact at vehicle centreline. Solid red line: median curve, dotted red lines: 10 and 90th percentile, grey curves: individual vehicle test results, Sedan only

Results for two vehicle categories (SUV and sedan) are shown in Figure 9 (‘all’). The red solid curve is showing the median force penetration curve, established from the median of each lateral impact location (denoted as LOC1 through LOC6).

In general, the structural responses are surprisingly different in the individual vehicles (see Figure 8). The median curves, however, clearly show different structural responses between load paths: i.e. a compliant spoiler, a bumper with increasing load levels starting at 70mm, and a BLE which offers substantial crush space at forces less than 10kN.

Please refer to the Appendix for a complete set of median loading and unloading curves for the vehicle category sedan (Figure 20 and Figure 21).
As indicated the impactor test regime was changed in the development of GVTRv1. The approach for establishing the median curves was modified, too:
- The CoHerent GV study median curves shown in Figure 13 and Figure 10 are based on centerline impacts only, while the ProPose GVTRv1 study median curves are based on centerline and five lateral offset impacts. This appeared sensible since the GVTR shall be representative in terms of the structural impact response over the entire width of the vehicle.
- The CoHerent GV study median curves are based on all vehicles, while the ProPose GVTRv1 study median curves are based on sedans only (for SUV and Sportscar separate median curves were established).

Given these differences the median curves of the CoHerent GV study (dotted curves) and the ProPose GVTRv1 study (dashed curves) still are quite similar – see Figure 10.
Designing and Manufacturing of GVTR v0

As mentioned in the introduction, the model shall be simple, to prevent any disparities between the virtual and physical model. Such, any machining, shape forming and joining (e.g. adhesive) shall be kept to a minimum. Ideally panels shall not be moulded or heat-formed, to ensure homogenous cross-sections and prevent any initial strains. The foam materials shall be extracted from the core of large EPP blocks, and all outer faces shall be machined consistently, to provide homogenous densities and interfaces properties (friction). Cavities in the EPP blocks shall be prevented.

The fasciae of real vehicle front ends are mostly made of polypropylene, being 2 to 3mm thick. The energy absorbers in bumpers are mostly made of expanded polypropylene (EPP) with densities between 30 and 60g/l. Hence it seemed reasonable to rely on these two materials only. Clearly there are other materials that might have been used for the purpose of energy absorption (i.e. tubes or honeycombs). The advantages of EPP (rebound characteristics, costs, robustness against dimensional tolerances, isotropy) are outweighing its drawbacks (weak dimensional accuracy, prone to fractures, …) by far.

The two components have distinct duties (see Figure 11):
- The EPP blocks shall replicate the structural impact response, i.e. the loading and unloading behaviour.
- The PP panels shall distribute forces and provide realistic frictional properties and a smooth contact interface.

Both, in GVTR v0 and v1 the panels are floating in the lateral direction. Attempts to fully constrain the panels at the outer edges revealed that a considerable amount of internal energy builds up in the PP panels. In that case not only the EPP but also the PP would contribute to the structural impact behaviour. From a standpoint of numerical modelling this is undesired: It would require that two accurate and fidelic material models are available. Further fully constrained panels distribute intrusions over a wider area in lateral direction. This in turn would require very slim EPP block cross-sections, that tend to buckle or break. Hence the panels were kept unconstrained in y-direction. To allow for oblique testing (i.e. the rig is rotated about its vertical axis), the panels can be locked at one side (see Figure 11).

To minimize the influence of density deviation within one foam block, the deformation elements are milled from the same defined positions each time (see Figure 12). Additionally, reference cubes are being made for material samples. Dimensional accuracy and weight of each block are documented by the manufacturer for quality check and validation.
RESULTS

In the following sub-chapters the results with GVTRv0 and v1 are summarized: (1) impactor testing (for GVTRv0 and v1), (2) study with aPLI and isolated leg (GVTRv0 only) and (3) repeatability (GVTRv0 only).

Impactor Testing
GVTR v0
For GVTR v0 the same corridors as those for the GV [5,6] were applied. Figure 13 shows the corridors for SPL (left), BMP (middle) and BLE (right). The brownish shaded areas show the loading-corridors (minimum to maximum). The light bluish shaded areas show the unloading corridors. Median loading and unloading curves are shown by brownish and bluish dotted lines, respectively. The green solid curve is showing the structural response of the current CoHerent GV. The red solid curve is showing the structural impact response of the GVTRv0.

While CoHerent GV is meeting the median force-penetration curve quite well, it is apparent that GVTRv0 is rather meeting the upper, the maximum corridor. This is by purpose: The numerical study indicated that the median corridors can be met quite well when using lower density foam blocks (EPP 30g/l). For the sake of robustness (to prevent failure or fracture in the BLE and SPL foam blocks) ACEA members opted for higher density foams. In case of the SPL loading ACEA members argued that the oblique loading of the spoiler (load case abbreviated with SPV) might overestimate the compliance (underestimate stiffness). Hence it was decided to employ higher density foams and to rather fit GVTRv0’s structural impact response to the maximum corridors.

Figure 13: Corridors for GVTR v0 and comparison of CoHerentGV and GVTRv0 force penetration behaviour [4]

GVTR v1
The numerical model of the GVTR v1 meets the target curves (median loading and unloading curves) fairly well – see Figure 14. For the sake of robustness (e.g. to prevent failure of the foam-blocks due to shear stresses or to prevent global buckling of the foam blocks), the maximum penetration was limited to 80mm for BLE and BMP, and to 100mm for the SPL.

These assumptions were based on a numerical study with the “ideal” GVTRv1, which met the median force-deflection curve up to 120mm (but which appeared critical in terms of foam failure in a real, physical test rig). It was found, that the maximum intrusions in simulations with HBM and aPLI (at 40kph impact velocity) against that ‘ideal’ GVTRv1 reached roughly 40mm in the BLE, 60mm in the grill area, 55 in the BMP and 65mm in the SPL area. Some additional crush space is provided for cases where tests are performed at higher impact velocities.
Figure 14: Behaviour of numerical GVTR v1 (solid) versus median loading and unloading curves (dashed)

Study with aPLI and isolated THUMS leg

The GVTRv0 allows comparing the response, the measurements and kinematics of various impactors and models side-by-side. The following models and impactors were employed in a first study (see Figure 15):
- aPLI model generously provided by ATD-MODELS as a pre-release beta (atd-aPLI-d00.11) [7],
- THUMS v4.02 positioned in gait posture according to EuroNCAP Technical Bulletin TB024 [6], i.e. the struck side leg trailing.
- THUMS isolated leg with upper body mass resembling the upper body mass of aPLI (leg posture consistent with THUMS in gait posture)
- aPLI physical legform impactor. Tests were conducted by Bertrandt.
- flexPLI physical legform impactor. Tests were conducted by Bertrandt.

aPLI and THUMS isolated leg are not identical in terms of length, mass and mass-distribution. Therefore various approaches were investigated (like scaling of the length and/or mass, alignment of hip, knee or sole, …), to allow for a side-by-side comparison with aPLI and flexPLI. Results of that comprehensive study will be published elsewhere. Here only two approaches will be shown: (1) The knee of THUMS isolated leg aligned (abbreviated as “knalgnd”) with the aPLI knee and (2) the ground aligned THUMS (assuming a sole-thickness of 25mm), abbreviated as “grnd”.

Figure 15 shows a comparison in terms of kinematics: In simulations with HBM we find that the knee rotates about the local x-axis first. Starting with 40ms the femur starts to rotate (about the long bone’s axis, i.e. the local y-axis), allowing for some flexion (local z-axis). In the isolated leg simulations, the rotation about the femur’s long bone axis induces a rotation of the upper body mass. Seemingly more rotation about vertical axis is induced in the ground aligned isolated leg test. In THUMS the rotation about the height axis is to the opposite direction and generally smaller.

In gVTRs numerical model we find more bending of the BMP panel in the unloading phase – possibly induced by the lateral translational joint. Based on these observations the height of the bumper panels in GVTRv1 was increased (as this did not occur in the other, higher panels).
To allow for a comparison in terms of x-moments about femur and tibia cross-sectional force/moment transducers were included (10 along tibia and femur, each). At each cross-section a local coordinate system, that is re-adjusted at each time-step, was introduced, with the y-axis pointing towards the knee and the z-axis.
pointing towards the struck side. For a comparison with aPLI those cross-sections, that were closest in ground-aligned THUMS in gait-posture to that of aPLI were selected. The sections at a height above ground of 812, 732 and 652mm were selected to resemble the Femur 3, 2 and 1 transducers in aPLI, respectively. For Tibia 1,2,3 and 4 the sections at a height of 383, 303, 223 and 143mm above ground were selected. In the knee aligned simulations, the selected cross-sections along tibia and femur in THUMS remained unchanged. In other words: The z-positions of the moment transducers in aPLI and in the ground-aligned THUMS (‘grnd’) are about the same. This is not the case in the knee-aligned THUMS (‘knalgnd’).

To measure the elongations of ligaments in THUMS, discrete elements along the ligaments’ edges were introduced. The total elongation was determined by averaging the elongation of the 4-5 ligament edges, which are calculated by adding up the elongations of each single discrete element along the edge. Clearly, there might be other reasonable approaches to that, but this seemed the most straight forward and reproducible approach.

It was found that the numerical model of aPLI, though being a beta version (atd-aPLI-d00.11), matches tremendously well in terms of moments measured in femur and tibia (curves not shown). Further it was found, that the femur moments determined in the THUMS isolated leg are matching very well in terms of peak-values (curves not shown). This is not the case in the tibia. Results will be published later.

When comparing the results of full THUMS (purple curve) and THUMS isolated leg (orange curve), it appears, that moments in the femur are higher in the isolated leg. The same is in the elongation of MCL.

When comparing the knee-aligned (grey) and the ground aligned (orange), it appears that the femur moments in the knee aligned are smaller, in particular next to the knee joint (Femur1). In tibia hardly any difference can be seen.

\[\text{Figure 16: Body Loads in experiments and numerical simulations against GVTRv0}\]

**Repeatability of GVTR v0**

GVTR v0 was used in tests with aPLI and FlexPLI. Results of three test repetitions (with FlexPLI) are shown in Figure 17. Moments in the tibia and femur as well as knee accelerations are practically identical up to approx. 60ms (that’s the time when FlexPLI hits the test-propulsion system’s gate during rebound). Repeatability appears excellent. In ligaments, though, differences in terms of elongation in the range of +/-10% can be found. It remains unclear, whether these are induced by GVTR’s design or arise from FlexPLI.
DISCUSSION

In the ACEA funded project ProPose and the EuroNCAP funded project CoHerent [4,8,9] multiple generic vehicles were established that allow to study the first phase of pedestrian and bicycle accidents. It seems worthwhile to briefly outline each of these models by chronological order, to understand their interrelation and purpose (see Table 1).

The first model was called “Generic Parameterisable Vehicle”, short GPV. The GPV’s shape as well as its structural impact response model (SIRM) is fully governed by parameters. In the GPV simple modelling techniques are employed, which feature high robustness and stability. The generic vehicle is separated into a number of contact areas (acronyms in brackets): Spoiler (SPL), Bumper (BMP), Grill (GRL), Bonnet Lead (BLE), Bonnet (BNT) and Windshield (WSH). The shape of each contact area (spoiler, bumper, a.s.o.) is governed by three Bezier-curves, approximating the shape of leading, trailing and centreline contour. The aim of GPV was to study the effect of shape and structural impact response characteristics on pelvic and upper femur loading [3].

The second model was called “Generic Vehicle”, short GV, and was developed for EuroNCAP [6]. The aim of the GV was to provide a vehicle fleet that can be used to compare Human Body Models in terms of head-trajectory and head contact timing (and such it was not developed to study leg loading). Bezier-curve parameters were fitted to replicate the median shape of a sample of European vehicles, covering four vehicle categories (SUV, family car, MPV and sportscar). The major difference between GPV and GV lies in the provision of modelling techniques available in all major explicit FEM codes (LS-Dyna, Radioss, VPS and Abaqus). Therefore the large-penetration contact was dismissed in favour of generic foams, with loading and unloading curves fitted to the median force-penetration behaviour of a sample of European vehicles.

The third model is called “Generic Vehicle Test Rig”, version 0. The aim of GVTR v0 was to provide a generic vehicle not only in numerical but also in physical environment for the validation of ATDs, like aPLI. By contrast to the aforementioned GPV and GV, the vehicle’s contour is not approximated through smooth Bezier controlled surfaces, but through simple planar surface segments. Further, the GVTR disregards the vehicle’s curvature in lateral direction. For the sake of robustness and repeatability concessions were made in terms of structural behaviour. Such, GVTR v0’s behaviour is on the “stiffer side”, providing a structural impact response stiffer than the median.

For version 1 of GVTR the structural impact response curves were re-established with a revised impactor testing regime, considering only FlexPLI compliant vehicles. Also vehicle shapes were re-established by determining the median BLE, BMP and SPL reference line for each vehicle category. More emphasis was laid on a close replication of median force-penetration behaviour. Additionally the load-path ‘bonnet’ was included. Furthermore, the experiences from the experiments with FlexPLI and aPLI against GVTRv0 have been
incorporated into the development (e.g. no gap between grill panel and grill EPP block, panel height for bumper increased).

Table 1.
Characteristics of the Generic Vehicles established in ProPose and CoHerent [3,4]

<table>
<thead>
<tr>
<th>Model</th>
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<th>Generic Vehicle</th>
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<th>Generic Vehicle Test Rig v1</th>
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<td>Parameterisable. 5 seed vehicles: Family Car (FCR), Old FC, MPV, SUV, Roadster</td>
<td>19 seed vehicles: Sedan (n=6), SUV (n=6), MPV (n=5) and Sportscar (n=2).</td>
<td>Sedan based on 6 seed vehicles</td>
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<td>Structure</td>
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<td>Deformable. Generic foam with load/unloading function fitted to median of 19 vehicles</td>
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<td>EPP foam, 30g/l Replicating median of 20 Flex-PLI compliant vehicles</td>
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<td>Force-Penetration Corridors</td>
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<td>Rigid cyl. impactor with 20 force transducers against SPL (oblique and horizontal), BMP, BLE – at centerline and 5 offset positions</td>
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Comparison of Vehicle Test Rigs

Generic Vehicle Test Rigs are not a novelty: Over the past 25 years researchers around the world, mostly for the purpose of PMHS testing, developed a considerable number of GVTRs [10–19]. Hence it appears worthwhile to compare the ProPose GVTR v0 and v1 with other test bucks used in research and development. Figure 18 shows a comparison of recent vehicle test rigs.
The structural response of test rigs cannot be directly compared, as the characteristics were established differently. Still, in an attempt to do so, Figure 19 shows the curves and corridors of various studies and test rigs in comparison with the GVTRv1 study. In the bumper region, the behaviour is similar to the Large Sedan buck. In the spoiler region, the behaviour is similar to the JSAE buck’s characteristic ‘A’. In the BLE region, the only similar behaviour was established by the CoHerent study.

**Figure 18. Comparison of Test Bucks with GVTRv1 in terms of geometry. [4,16,18,19]**

**Figure 19: Comparison of other Test Bucks with GVTRv1 in terms of structural response [4,11,18–21]**

**CONCLUSIONS**

GVTRv0 is a test-rig that proved to be a very robust, highly repeatable, fidelic, simple, easy-to-use and low cost tool for the validation of ATDs, while still providing a realistic loading of the pedestrian. It closes the gap between numerical and experimental world.

GVTRv1 features improvements over the GVTRv0:
- The additional loadpath bonnet was included,
- two additional vehicle categories are covered,
- the structural impact response is replicating the latest Flex-PLI compliant vehicles,
- the structural impact response is replicating the median instead of the maximum force-penetration behaviour.

As for now GVTRv1 sedan is available only in numerical environment. It will be available in summer 2019 for experiments. Two other vehicle categories will be introduced: SUV and sportscar.
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REFERENCES


**APPENDIX**

Figure 20: Median loading and unloading by horizontal and vertical (LOC1..6) impact location for Sedan. Areas ‘All’
Figure 21: Median loading and unloading by horizontal and vertical (LOC1..6) impact location for Sedan. Areas ‘Only’