PARAMETRIC STUDY USING THE OLC AND SPÜLL TO QUALIFY THE SEVERITY OF THE FULL-WIDTH RIGID TEST AND DESIGN AN IMPROVED FRONT-END

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ABSTRACT

Self-protection of car occupant is a crucial topic all over the world. Restraint systems have to be designed to protect various sizes of occupants involved in several type of crash and therefore several types of crash pulses.
Considering the additional constraints applied on the car design these days (CO_2 emission and therefore mass reduction, or reduction of front overhang) improvements and optimisation on the car structure are needed to better control the pulse. Otherwise, if the pulse is too severe, it will be difficult to design adequate restraint systems.

PSA Peugeot Citroën launched a large programme with physical crash tests and modelling on the full-width rigid barrier test.
This was applied to several types of cars and car architecture (small family, large family cars).
The 8 x 16 (128) load cell wall was used in each crash test to get a lot of measurements essential for the correlation of the numerical models.

The physical crash tests permitted to identify the contribution of each load path on OLC and spüll (pulse severity). The load paths analysed are the subframe, the side members, the engine, the upper structure of the body in white...
These tests were used to create correlated numerical model of each car size or architecture.
Then, correlated crash simulations were used to carry out a parametric study via changing the impact speed, mass, subframe stiffness, longitudinals stiffness, engine size and position.
This parametric study helped in defining the major contributors for each car size or architecture.

As expected, the influence of car mass and test velocity were highlighted to have a similar equivalent consequence on the severity of the crash (OLC and Spüll severity) whatever the car size or architecture.
But for other parameters such as subframe stiffness, longitudinals stiffness, engine size and position, it was surprising to see that their influence is not as high as expected.
One last surprising result is to see that front end internal components have a low influence on the pulse severity with respect to the stiffness of the components in charge of transferring the load from the front end to the cockpit and subframe.

INTRODUCTION - AIM OF THE STUDY

Frontal impact on a rigid obstacle are the most severe impacts with respect to change of velocity (deceleration) sustained by the occupants.
This test configuration will be used worldwide in the near future (already in China [1], Korea, Japan, USA [2] + possible new regulation on frontal impact and Euro NCAP 2015 [3]). It will also be used with more demanding biomechanical criteria designed to better protect vulnerable users.
In parallel, the new constraints applied on CO_2 emission imply a huge work on mass reduction. And the current trend in car designs requires a reduction of front overhang.
These features have a negative effect on passive safety: they increase the pulse severity in frontal impact when the full width of the car is involved.
In order to control the pulse severity and achieve a good passive safety protection level, PSA Peugeot Citroën launched a programme to identify the main parameters that influence the car deceleration.
Test programmes and numerical analyses on several types of vehicles were carried out.
Mixed results were found. Some car structures do not need to be changed to reach a good passive safety performance in this new test and occupant characteristics. But others would naturally reach a too high level of acceleration and need to be improved to limit the pulse to be able to correctly protect the occupants.
This paper presents the study on these latter vehicles focusing on 2 architectures: small car and sedan car.

METHOD

A test programme was carried out in order to correlate numerical models. These numerical models were then used to assess the most influent parameters via parametric studies.

In addition to the standard parameters such as load cell wall forces, B-Pillar pulse, velocity and displacement, two other parameters were used in the analysis. They are presented below.

Analysis was made on several cars, but this paper details the results found on the small car, and gives the overall conclusion for the sedan car as well.

Deceleration severity criteria: OLC and SPÜLL

To assess the severity of the change of velocity in a frontal impact, we are using two criteria. The first one is the spüll.
Its definition is:

$$\text{Spüll} = v^2/t \qquad (1).$$

where t is the impact duration, and v is the vehicle velocity calculated via the acceleration (with v(t=0)=0). Unit of spüll is W/kg.

The second criterion is OLC (Occupant Load Criterion) [4], defined as shown in Figure 1.

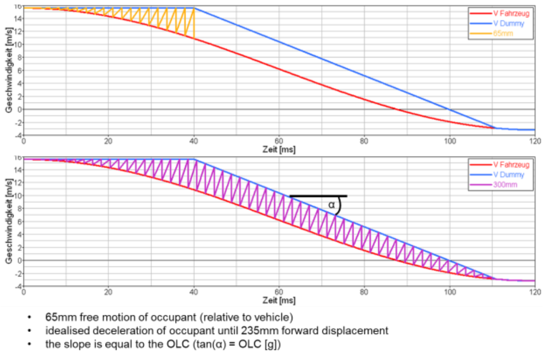


Figure 1. OLC definition

OLC has the same dimension as an acceleration and its unit is in G (G = 9.8 m/s²).

PHYSICAL TESTS

Test configuration

For our test programme, an instrumented rigid wall 126 load cells) was used (see Figures 2 and 3). It should be note that 2 cells were missing with respect to the standard 128 load cell wall: the extreme bottom left and the extreme top right load cells.

Figure 2. Load cell wall.

A1	B1	C1	D1	E1	F1	G1	H1	I1	J1	K1	L1	M1	N1	O1	
A2	B2	C2	D2	E2	F2	G2	H2	I2	J2	K2	L2	M2	N2	O2	P2
A3	B3	C3	D3	E3	F3	G3	H3	I3	J3	K3	L3	M3	N3	O3	P3
A4	B4	C4	D4	E4	F4	G4	H4	I4	J4	K4	L4	M4	N4	O4	P4
A5	B5	C5	D5	E5	F5	G5	H5	I5	J5	K5	L5	M5	N5	O5	P5
A6	B6	C6	D6	E6	F6	G6	H6	I6	J6	K6	L6	M6	N6	O6	P6
A7	B7	C7	D7	E7	F7	G7	H7	I7	J7	K7	L7	M7	N7	O7	P7
	B8	C8	D8	E8	F8	G8	H8	I8	J8	K8	L8	M8	N8	O8	P8

Figure 3. Illustration of load cell wall and numbering.

Test analysis: load cell wall break down

As shown in Figure 4, the efforts sustained by each load cell are measured throughout time.

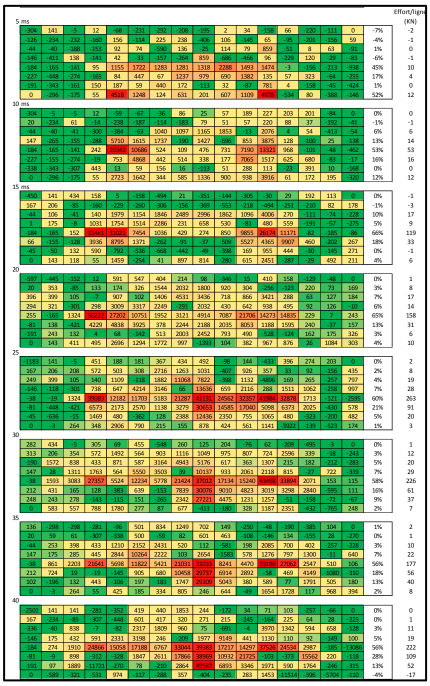


Figure 4. Load breakdown

For the analysis, some cells are grouped together (we used the numbering presented in Figure 2):

- Left longitudinal: cells D[4…6]+E[4…6]+F[4…6]
- Right longitudinal: cells K[4…6]+L[4…6]+M[4…6]
- Engine block: cells G[3…7]+H[3…7]+I[3…7]+J[3…7]

This grouping helps to analyse the contribution of the main load path throughout the impact (see Figures 5 and 6).

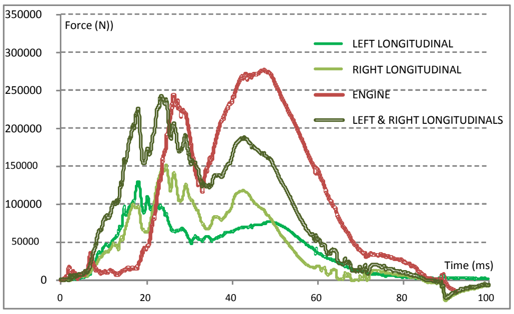


Figure 5. Load (in N) throughout time –small car

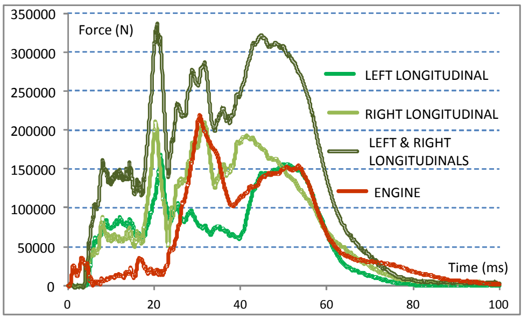


Figure 6. Load (in N) throughout time –sedan car

One can notice easily that the breakdown is different between the two architectures.

For the small car, the longitudinals contribution is predominant in the first part of the impact (up to 25 ms). Then the engine block load path (GMP) is the major contributor up to the end of impact.
It can be guessed that it is the stopping of the engine that is essential in the vehicle deceleration.

For the sedan car, the breakdown is radically different even if the longitudinals contribution is predominant in the first part of the impact. Indeed, the engine block load (GMP) is never higher than the longitudinals. And between 40 to 60 ms the ratio is 1:2. Therefore, on the sedan architecture, the longitudinals are essential to stop the vehicle.

Use of the Spüll to quantify and confirm the contribution of the load path of the overall vehicle deceleration

In order to link the contribution of each load path to the overall vehicle deceleration, a study was carried out using the steps described below.

Calculation of the effective mass

We used the average of the two B-Pillar accelerations to calculate the vehicle velocity.

From this vehicle velocity (v_{veh}) and from the effort measured on the load cell wall, we can calculate the effective mass M(t) :

$$M(t) = 2/v_{veh}(t)^2 \, (E_{max} - \int F(t).\ v_{veh}(t)) \quad (2).$$

where $E_{max}=MAX\ (\int F(t).\ v_{veh}(t))$

Figure 7 presents the evolution of the effective mass throughout the impact.

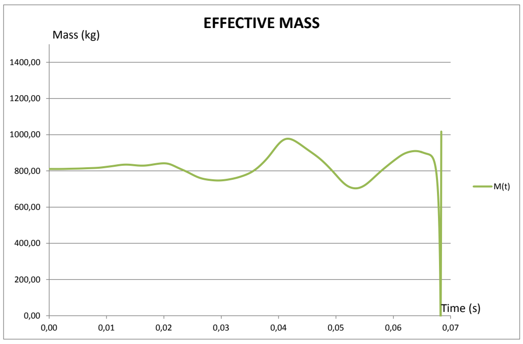
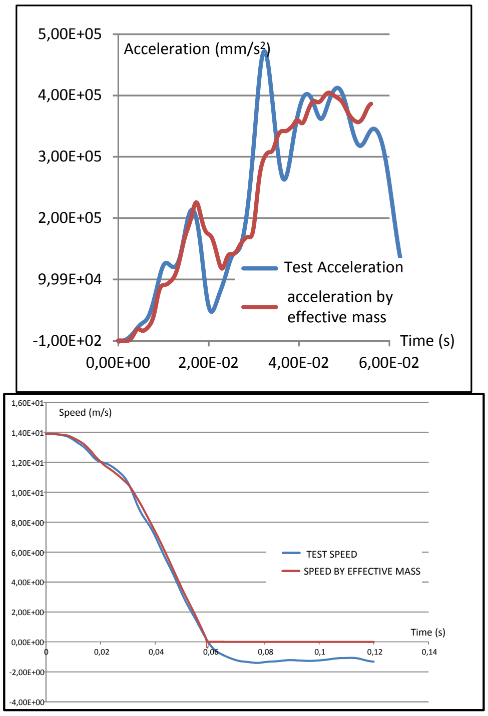


Figure 7. Evolution of effective mass throughout time

Check of the calculation of the effective mass

To check the calculation of the effective mass, we reckon the vehicle main mechanical parameters (acceleration, velocity and displacement) from the effective mass.
Acceleration is reckoned via F(t)/M(t).
Velocity is the simple integration of acceleration.
Displacement is the simple integration of velocity.
Figure 8 shows that this calculation is acceptable.



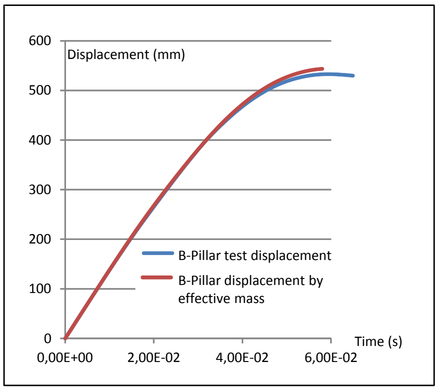


Figure 8. Check of the calculation of the effective mass

Calculation of each load path acceleration

From the effective mass and the load path forces measured on the wall, it is possible to reckon an acceleration for each load path.

For the load path i, the acceleration is given by:

$\gamma_i(t) = F_i(t) / M(t)$

Five main load paths were identified: the 2 longitudinals, the subframe, the engine block effort on the firewall, and the superstructure. The corresponding load cells are shown in Figure 9.

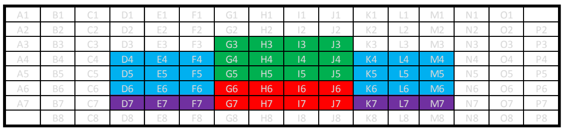


Figure 9. Corresponding load cells for each of the five main load paths (light blue = longitudinals x 2, red = subframe, green = engine block, purple = superstructure).

The integration of these accelerations leads to the change of velocity, called DV, of each load path. One can notice in Figure 10 that the sum of DV is very close to the overall vehicle DV. This means that we did not forget a major load path.

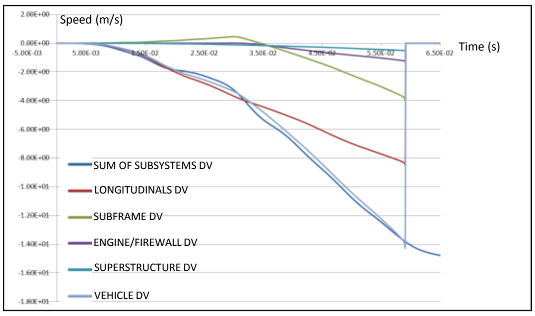


Figure 10. Comparison between sum of DV and vehicle DV.

Calculation of the spüll for each load path

Thanks to the DV, we can come back to the overall spüll and highlight the relative contribution of each load path as percentages by this formula:

Spüll = $(\Sigma_i DV_i)^2/t$ avec i = subsystem

Applying these steps to the small and sedan vehicles gives the breakdown shown in Figures 11 and 12.

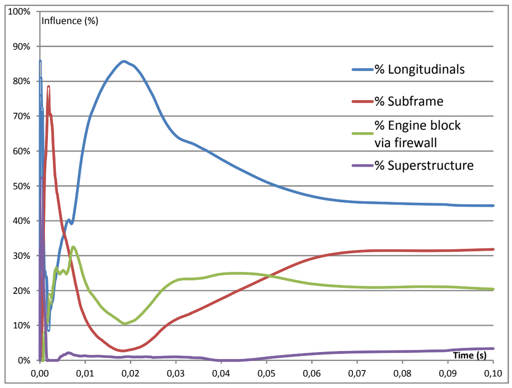


Figure 11. Small vehicle test – percentages of each load path on the overall spüll throughout time.

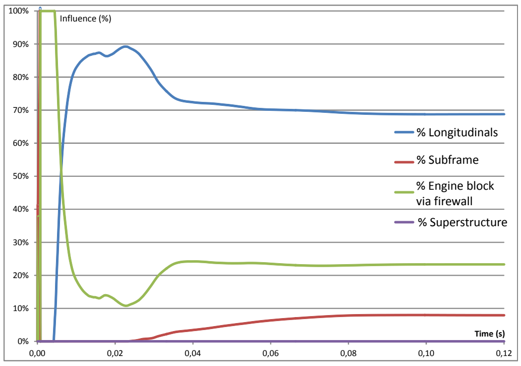


Figure 12. Sedan vehicle test – percentages of each load path on the overall spüll throughout time

At the end of the impact, the contribution of each load path on the overall Spüll is given in Table 1

Table 1.
Contribution of each load path on the overall spüll for small car and sedan car

Breakdown (%) end of test	Small car	Sedan car
Longitudinals	44	69
Subframe	32	8
Engine on firewall	20	23

The percentages are correlated to the level of force measured. Therefore, we can state that for the small car architecture the major contributors on the pulse severity are the engine block stopping in the firewall and the subframe; whereas for the sedan car architecture it is the longitudinals.

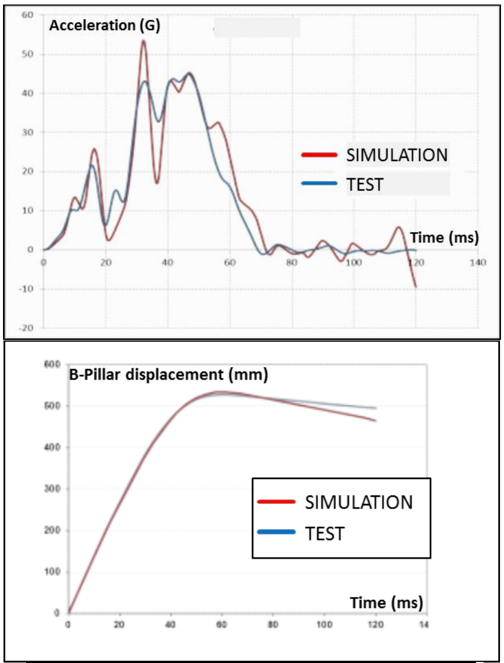
NUMERICAL MODELS CORRELATION

Numerical models of the two car architectures were created and correlated in terms of overall behaviour

(B-Pillar deceleration) but also in terms of relevance of the different load path behaviour.
The following details the results found on the small car. And later, we will give the overall conclusion for the sedan car as well.

Overall behaviour correlation

Figure 13 presents the overall deceleration measured in the physical test and compared with the numerical model for the small car. The attached table shows the main parameters: acceleration peak, OLC, time of DV=0, Spüll and time of Spüll max.



	Decel max. (g)	OLC	DV=0 Time (ms)	SPULL (W/kg)	SPULL max time (ms)
Test	48.3	31.7	62.0	3202	63.2
Simulation	53.7	32.0	59.9	3321	65.2

Figure 13. Small car – comparison of physical test vs numerical test on the overall parameters.

The level of correlation of the small car numerical model is really good when looking at the overall parameters.
Let's have a look now at the level of correlation of specific components: the load paths identified previously.

Representativeness of the load path contribution on the pulse severity criteria

The full load cell wall was numerically modelled (see Figure 14) in order to:

- Compare the overall force mesasured in the physical crash test to the numerical measurement. This will be done by comparing the force-displacement curves
- Compare the breakdown into the different load paths as calculated earlier with the ones reckoned via the parameters available in the numerical model

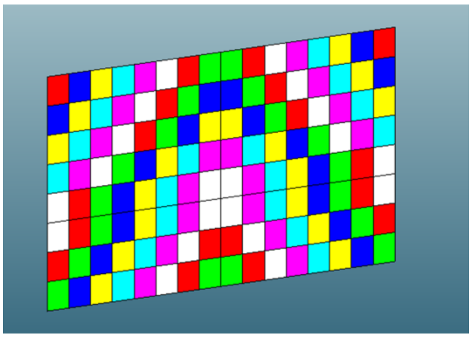


Figure 14. Modelling of the full-width rigid frontal impact test: load cell wall with its 128 load cells.

The comparison between physical test and simulation for the small car of the overall load cell wall force vs. car displacement is shown in Figure 15.

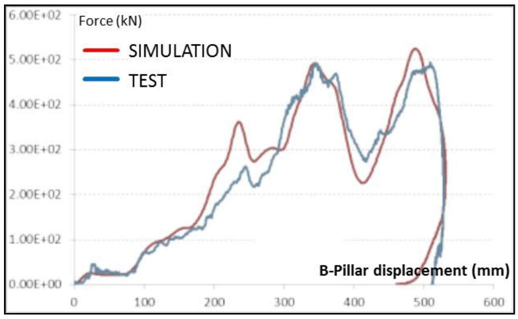
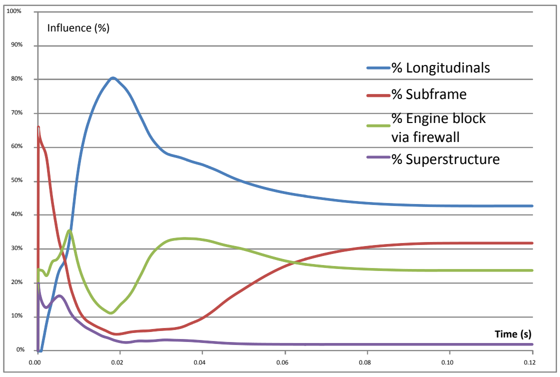


Figure 15. Small car – comparison between physical test and simulation of the overall load cell wall force vs. car displacement.

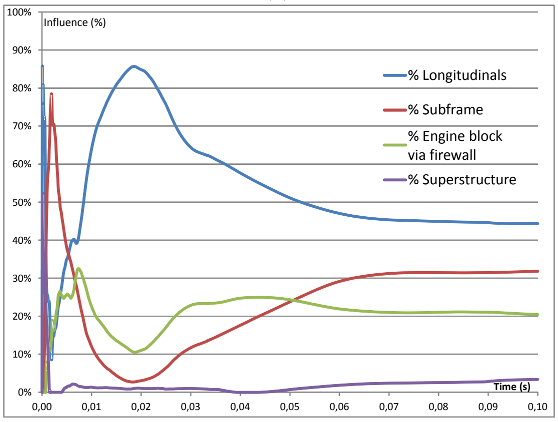
Here again, the small car model gives very good correlation: the chronology is very similar –the peaks occur at the same overall vehicle compression - as well as the magnitude, except for the first peak which magnitude is higher for simulation.

If we look at the breakdown and contribution of the main load paths on the results of Spüll, we also have good correlation.

Figure 16 presents the breakdown in percentage of each load path to the overall Spüll for the numerical model (a) and for the physical test (b). Comparison between Figure 16 (a) and Figure 16 (b) shows that the breakdown as assessed in the physical test via indirect measurement is confirmed via the parameters available in the numerical model.



(a)



(b)

Figure 16. Small vehicle – contribution in percentages of each load path to the overall Spüll throughout time for the numerical model (a) and for the physical test (b).

This comparison between physical test and numerical model and the confirmation of the breakdown between load paths is summarized in Table 2 via the percentages of contribution at the end of the impact.

Table 2.
Contribution of each load path on the overall spüll at the end of crash for small car – comparison between physical test and numerical model

Breakdown (%) end of crash	Small car test	Small car Simulation
Longitudinals	44	43
Subframe	32	32
Engine on firewall	20	24

This part of the study allows us to state that the small car model is good to be used for a parametrical study because its level of correlation is very good.

PARAMETRICAL STUDY

We already presented the two mechanical parameters we use to translate the impact severity (OLC and Spüll) of a crash.
In order to know what are the car architecture parameters that we need to control to be able to design an ideal car architecture, we need to carry out a parametrical study on these parameters.

Method

We only focused at the individual influence of each parameter. The combination of parameters variations will be studied later.
The parameters linked to the car architecture and design are:

- car mass
- longitudinals force level
- subframe force level
- tunnel force level
- size of engine block
- firewall location
- subframe front end location

They are presented more in details in the next chapter. Then we will present the results of their variation.

The variation made were always realistic ones that could be applied in a car design. And every time the intrusion level was checked to ensure that the global car synthesis was still realistic and acceptable.

Presentation of the parameters and their variation

Change of car mass

There are increasing constraints throughout the years about CO_2 emission. This implies a huge work on car architecture to reduce their weight. Therefore we decided to analyse a 100 kg of mass reduction.
On the other hand, a same car architecture / platform can host a heavier superstructure (SW or SUV variants) and / or a heavier powertrain (Hybrid engines). This is why we also studied a 200 kg of mass increase.

Change of longitudinals force level

In the first part of our study, we highlighted that the longitudinals are one of the major contributors (or even the major) on the Spüll magnitude.
Therefore the longitudinals force level had to be part of this parametric study.
For the small car, we applied a +/- 20% variation.

<u>Change of subframe force level</u>

The contribution of the force transmitted from the engine block to the subframe is 32% on the Spüll for the small car as shown previously in Table 2. Here again, we applied a +/- 20% variation.

<u>Change of tunnel force level</u>

The tunnel plays an important part in the transfer of the front-end forces to the understructure and the cockpit. Therefore, we decided to study the influence of an increase of 20% on the force of the front-end zone of the tunnel.

<u>Change of size of engine block and its location</u>

It is natural to feel that the size of the engine block is of high importance to control the pulse severity as its impact on the wall should influence the time needed to stop the car, but also because the firewall will not sustain any load before the engine block starts to contact it.

This is why we decided to modify its volume via a change of +/- 50 mm in the engine + gear package.

Another independent modification was made on its location: variation of +/- 50 mm.

<u>Change of firewall location</u>

As already explained for the engine block, we applied the same reasoning to the firewall location. Again, we applied a +/- 50 mm variation in the zone of contact between the engine block and the firewall.

<u>Change of subframe front-end location</u>

Same reasoning on the subframe front-end location applied to the contact between the subframe and the engine block. But, we only use a +50 mm change.

Results

The detailed results presented here are the ones obtained for the small car architecture.

The colour code used in the following tables helps to identify the variation in percentage with respect to the reference model.

Throughout this paper, the colour code is the same:

- green means variation 10% or below
- yellow means variation between 11% and 20%,
- orange means variation between 21% and 30%,
- red means variation equal or above 30%.

<u>Change of car mass</u>

We took into account a variation of - 100 kg and +200 kg with respect to the reference model. Results are presented in Table 3

Table 3.
Influence of car mass on OLC and Spüll parameters

		REFERENCE	MASS INFLUENCE							
			-100 kg	% difference	-50 kg	% difference	+20 kg	% difference	+100 kg	% difference	+200 kg	% difference
OLC (g)	RIGHT	32,5	32,9	1%	32,3	-1%	32,1	-1%	31,9	-2%	30,9	-5%
	LEFT	32,2	32,4	0%	32,0	-1%	31,9	-1%	31,8	-1%	31,0	-4%
SPULL (W/kg)	RIGHT	3464,1	3520,0	2%	3445,8	-1%	3383,5	-2%	3219,8	-7%	3065,7	-12%
	LEFT	3309,1	3400,2	3%	3328,1	1%	3233,9	-2%	3148,0	-5%	3011,9	-9%

Impact weight does not have a strong influence on OLC. A difference of 300 kg would change OLC by 4% only (for the left OLC, the one obtained with the left B-Pillar). Differences on the Spüll are stronger, with a maximum increase of 15% on the right Spüll. Influence of mass is only visible on Spüll.

If we analyse the curves, relationship between vehicle mass and OLC or mass and Spüll is linear and negative (see Figure 17).

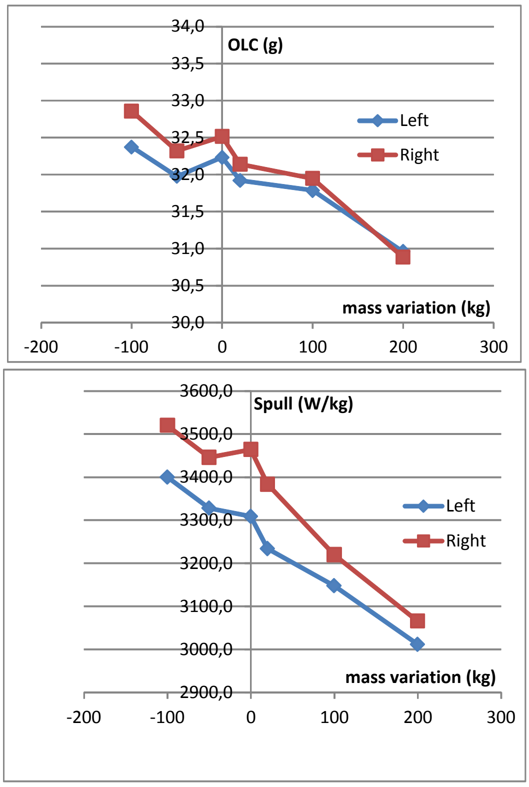


Figure 17. OLC and Spüll trends with respect to vehicle mass.

We can state that a decrease of 10 kg in the vehicle mass would increase the Spüll by 14 W/kg.

After the study of the initial condition parameters, we can pass on the influence of the load-path force levels. It is expected that if the energy is absorbed faster because the load path are stronger, the stopping of the car will be different and therefore the change of velocity (<=> pulse severity) sustained in the cockpit will be modified.

Change of vehicle design - longitudinals force level

We already stated that the longitudinals are the major contributors to the Spüll at the end of impact. We therefore expect a strong influence of the longitudinals force level on the pulse severity.

Table 4 presents the results and Figure 18 shows visually the trends.

Table 4.
Influence of longitudinals force level on OLC and Spüll parameters

		REFERENCE	LONGITUDINALS FORCE INFLUENCE			
			+20%	% difference	-20%	% difference
OLC (g)	RIGHT	32,5	32,0	-2%	32,7	0%
	LEFT	32,2	31,3	-3%	32,4	1%
SPULL (W/kg)	RIGHT	3464,1	3377,9	-2%	3254,9	-6%
	LEFT	3309,1	3258,0	-2%	3166,2	-4%

Only the peaks of deceleration show a moderate influence of the longitudinals force level. The other parameters are not or very little modified.

Figure 18 shows that it is not possible to highlight an obvious trend with OLC or Spüll.

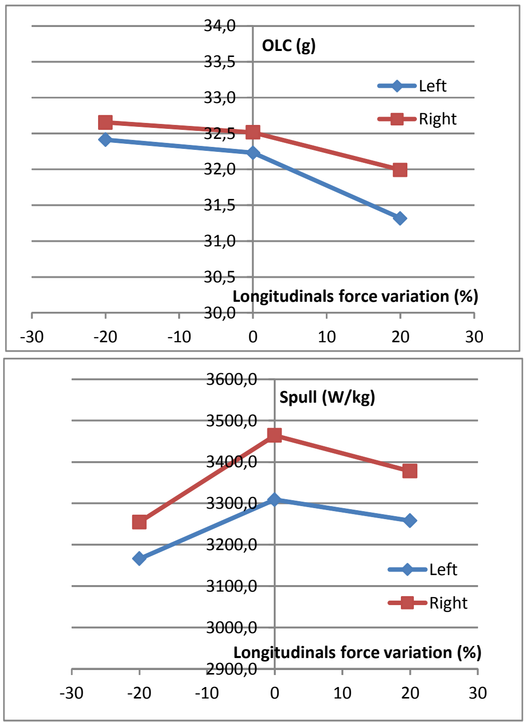


Figure 18. OLC and Spüll trends with respect to longitudinals force level

Contrary to what was expected, a strong change in the longitudinals force level will not strongly affect the pulse severity as measured via OLC and Spüll. In order to explain it, we compared the longitudinals (left and right) kinematic of the three models as shown in Figure 19.

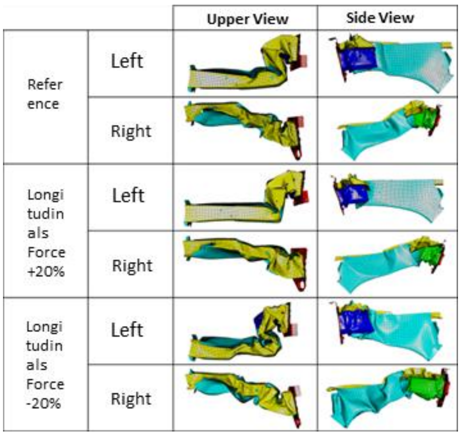


Figure 19. Longitudinals (left and right) kinematic of the three models

The kinematics are quite similar and we guess this is the reason why the pulse severity parameters we not changed by a +/-20% change in the longitudinals force level.
Indeed the energy absorption performance definitely depends on the kinematics (overall rotation or buckling) more than on the stiffness of the beam. This should be studied in a future research work on the topic.

Change of vehicle design - subframe force level

Table 5 presents the results shows visually the trends of the influence of the subframe force level on the pulse severity.

Table 5.
Influence of subframe force level on OLC and Spüll parameters

		REFERENCE	SUBFRAME FORCE INFLUENCE			
			+20%	% difference	-20%	% difference
OLC (g)	RIGHT	32,5	32,6	0%	30,0	-8%
	LEFT	32,2	32,4	1%	29,8	-8%
SPULL (W/kg)	RIGHT	3464,1	3351,4	-3%	3131,9	-10%
	LEFT	3309,1	3259,5	-1%	3063,9	-7%

The results are outstanding. If an increase of 20% in the subframe strength almost gives no change to Spüll and OLC, the same amount of decrease as a strong influence. The consequence is a decrease by 8% of OLC and 10% for Spüll.
This can be explained by an increase in compressibility offered by the softening of the subframe that decreases the deceleration.
On the contrary, stiffening the subframe do not change a lot the deceleration, because the reference model is already strong enough and do not offer a lot of deformation.

We can conclude that the softening of the subframe can be a key action to make if the deceleration needs to be decreased.

Change of vehicle design - tunnel force level

The last force level we decided to modify was the tunnel one. Table 6 presents the results.

Table 6.
Influence of tunnel force level on OLC and Spüll parameters

		REFERENCE	TUNNEL FORCE INFLUENCE	
			+20%	% difference
OLC (g)	RIGHT	32,5	32,6	0%
	LEFT	32,2	32,2	0%
SPULL (W/kg)	RIGHT	3464,1	3470,7	0%
	LEFT	3309,1	3290,6	-1%

An increase of the tunnel force level would not influence the pulse severity.

As a partial conclusion, we can state that the change in the load-path force level did not give the trends we expected. The only significant influence highlighted was the softness of the subframe that would decrease Spüll and OLC values.

We already quantified the influence of initial test conditions and of load-path force levels. Now we can pass on the influence of the load-path locations or size. These changes are expected to have an influence on the stacking and therefore on the timing, thus on the maximum severity of the pulse sustained in the cockpit.

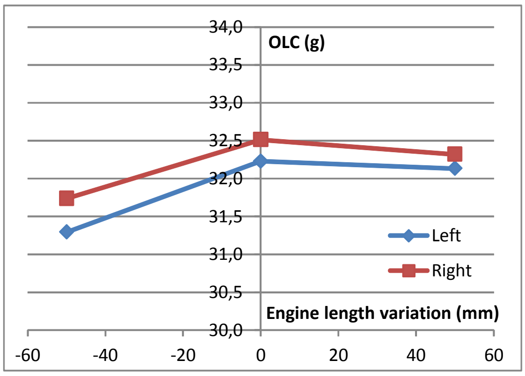
Change of vehicle design - size of engine block

The first parameter studied was the engine block size and the results are presented in Table 7.

Table 7.
Influence of size of engine block on OLC and Spüll parameters

		REFERENCE	ENGINE LENGTH INFLUENCE			
			+50 mm engine length	% difference	-50 mm engine length	% difference
OLC (g)	RIGHT	32,5	32,3	-1%	31,7	-2%
	LEFT	32,2	32,1	0%	31,3	-3%
SPULL (W/kg)	RIGHT	3464,1	3347,7	-3%	3407,9	-2%
	LEFT	3309,1	3274,2	-1%	3251,8	-2%

There is little effect of the engine block size and no specific trend as shown in Figure 20.



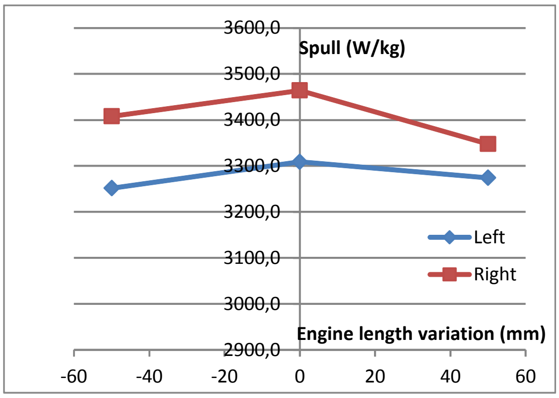


Figure 20. OLC and Spüll trends with respect to engine block size

The consequences on overall vehicle behaviour for the small car are surprising. If an increase in intrusion occurred due to a larger engine block can explain partially these results, we expected more severe level of deceleration than the one measured.

Change of vehicle design - firewall location

The second parameters that should influence the stacking and therefore the pulse severity is the firewall location. We looked at the location in front of the engine block zone of contact. We did not change the longitudinals location.
Table 8 presents the results.

Table 8.
Influence of firewall location on OLC and Spüll parameters

		REFERENCE	FIREWALL LOCATION INFLUENCE			
			50 mm X forward firewall location	% difference	50 mm X rearward firewall location	% difference
OLC (g)	RIGHT	32,5	31,7	-2%	32,5	0%
	LEFT	32,2	32,0	-1%	32,1	0%
SPULL (W/kg)	RIGHT	3464,1	3271,9	-6%	3431,0	-1%
	LEFT	3309,1	3224,3	-3%	3305,5	0%

Shifting the firewall rearward would not influence the criteria. But shifting it forward seems to improve Spüll and OLC.

To shift it forward, on the small car, we increased by 50 mm the firewall cross beam section as shown in Figure 21.

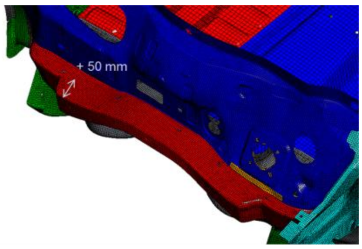


Figure 21. How we did the firewall shift forward on the small car.

A detailed look at the firewall cross beam in the model is given in Figure 22 and it shows that this element is significantly deformed.

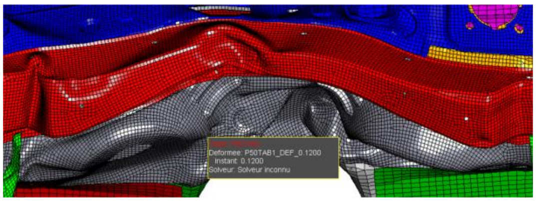


Figure 22. small vehicle model – deformation of the firewall cross beam when the firewall is put 50 mm forward

This means that the firewall was actually not shifted by 50 mm. but this also means that the stiffness/compression behaviour of the impact between the engine block and the firewall central beam was modified.
Therefore, this model allows us to state that the stiffness of the zone of impact between the firewall and the engine block has an influence on the Spüll and on the OLC for a frontal full-width impact.

Change of vehicle design - subframe front-end location

The third parameter on the stacking was the subframe front-end location. Only one value was assessed: a shift of 50 mm rearward of the front-end of the subframe. Table 9 presents the results.

**Table 9.
Influence of subframe front-end location on OLC and Spüll parameters**

		REFERENCE	SUBFRAME FRONT-END LOCATION INFLUENCE	
			50 mm X rearward subframe front-end location	% difference
OLC (g)	RIGHT	32,5	31,6	-3%
	LEFT	32,2	31,6	-2%
SPULL (W/kg)	RIGHT	3464,1	3287,1	-5%
	LEFT	3309,1	3213,0	-3%

This shift of 50 mm rearward of the front-end of the subframe decreases slightly the pulse severity.

This statement combined with the subframe force level one makes us conclude that to improve the small car, it is needed to re-design the subframe to better control OLC and Spüll.

Change of vehicle design - engine block location

The last parameter analysed in this study is the engine block location.
We applied a +/- 50 mm shift without changing the suspensions.
Table 10 presents the results for the small car.

Table 10.Influence of engine block location on OLC and Spüll parameters

		REFERENCE	ENGINE BLOCK LOCATION INFLUENCE			
			50 mm X forward	% difference	50 mm X rearward	% difference
OLC (g)	RIGHT	32,5	32,1	-1%	31,6	-3%
	LEFT	32,2	31,5	-2%	31,7	-2%
SPULL (W/kg)	RIGHT	3464,1	3415,1	-1%	3285,9	-5%
	LEFT	3309,1	3310,9	0%	3184,5	-4%

Shifting the engine block forward has very little influence on pulse severity.
Shifting it rearward is good for OLC and especially for Spüll. This is due to the fact that the level of deceleration is lower at the beginning of the crash and the impact duration is increased (2 ms more than the model of reference).
Therefore the engine block location is also a key parameter to control the pulse severity.

DISCUSSION AND LIMITATIONS OF THE STUDY

If we want to summarize the results presented in the previous chapter, we can have a look at the table below (Table 11).

Table 11. Summary of the analysis : effect of a change (delta) of magnitude in the highlighted parameters on OLC and Spüll parameters for the small car

Parameter	Delta param.	Deceleration	
		Decrease of parameter	Increase of parameter
Mass	*100 kg*	-	+
Subframe force level	*5 T*	++	-
Longitudinals force level	*2 T*		
Tunnel force level	*2 T*		
Engine block volume	*50 mm*	+	---
Firewall location	*20 mm*	+	--
Front-end subframe location	*20 mm*	+	
Engine block location	*20 mm*	--	+

And if we extend this summary to other car architectures not presented in details here, we can state that some parameters have strong influence on the pulse severity measured on a full-width rigid frontal impact. But depending of the characteristics of the reference model, some parameters do not need to be tuned because they are stiff or soft enough since the beginning. As an example, Table 12 presents the results for the sedan car.

Table 12.Summary of the analysis : effect of a change (delta) of magnitude in the highlighted parameters on OLC and Spüll parameters for the sedan car

Parameter	Delta param.	Deceleration	
		Decrease of parameter	Increase of parameter
Mass	*100 kg*	-	+
Subframe force level	*5 T*		
Longitudinals force level	*2 T*		
Tunnel force level	*2 T*		-
Engine block volume	*50 mm*	++	---
Firewall location	*20 mm*	+	--
Front-end subframe location	*20 mm*		
Engine block location	*20 mm*	-	+

On the other hand, there are some limitations that we should stress.
First of all, each parameter was assessed independently of the others whereas the combination could be logical and have a cumulative effect that could be non-linear.
A future analysis is planned to investigate the influence of combining the key parameters highlighted here.

A second limitation concerns the longitudinals. It was unexpected to see so little influence of the longitudinals stiffness on the pulse severity. It is guessed that an additional parameter: the change in the longitudinals kinematics would be of interest. The future analysis will take this into account as well.

Finally the consequence of changing or optimizing these key parameters to soften the pulse on the other type of impacts should also be assessed.
It is obvious but it is always good to stress that the design of a car in terms of passive safety is always a compromise between stiffness and intrusion. Other type of crash (partial overlap) would increase the level of intrusion. The cockpit should always be preserved and intrusion strongly controlled.

CONCLUSION

This entire study was made to define the key parameters influencing the pulse severity measured in the cockpit on a full-with rigid 0° frontal impact.

The pulse severity was assessed via two scalars: OLC and Spüll that are used to design the restraint systems for different car architectures and for different type/age of occupants.

Tests were carried out on a fully instrumented load cell wall. These tests allowed us to get well correlated numerical model. In a first step, these models helped to identify the "a priori" key parameters that would influence the pulse severity via the study of their contribution to the overall Spüll.
Once these parameters were highlighted, the second phase of the analysis was to carried out a parametrical study to highlight the actual key parameters.
Some parameters were expected to be of first order and finally were not so influent. Others were highlighted and will be optimised to reach a satisfying pulse severity.
If we list the actual key parameters, we have:

- The subframe stiffness
- The firewall position
- The front-end position of the subframe

These are the ones linked to the kinematic behaviour of the engine block.

Finally, the longitudinals stiffness did not bring what was expected, and a further study is needed. It should aim at quantifying the influence of the key parameters when combined. And it should also aim at studying an additional parameter: the longitudinals kinematics.
This will be carried out in 2013 by PSA Peugeot Citroën.

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