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Vehicle Body Engineering Approach of Some SUV for Small Overlap

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Abstract:

***Background*:** Small Overlap (SOL) in IIHS is aggressive for most vehicles. Most of OEMs struggled to improve the performance for SOL. The Rating of most vehicles in SOL is not reasonable, although which can rate 5 star for US-NCAP.

***Objective*:** Find feasible solutions adapted to current designed SUV to have a 'good' rating of structure assessment.

***Method and Material*:** Via Review the results of Small Overlap Oblique released by IIHS, feasible engineering solutions are concluded to have 'good' rating of structure assessment for SOL. Then it is adapted to the designed SUV. A full vehicle LS-DYNA model is generated to verify the countermeasures.

***Results*:** For most of the vehicle have 'good' rating, the following characters could be summarized: a. the vehicle pass by the rigid barrier, b. the tire will drop off the vehicle or the tire rim breaks, c. large enough curtain airbag to protect the head of occupant from impacting on hard components. the vehicle compartment deformed merely. Above key phenomena is reproduced well by the designed vehicle via employing the failure of the connections to wheel anchor and the tire rims.

***Conclusions*:** The tire dropping off or rim breaking reduce the load transferred to rocker, increase the deformable space and the deformation of vehicle body become smaller, which not only lead to 'good' rating of structure assessment, but also create the pre-condition for 'good' rating of occupant protection due to more friendly impacting pulse.

Keywords: Car body design, Crashworthiness, Small Overlap, IIHS

1 Introduction

It is known that New Car Assessment Program (NCAP) contributes a lot to improving safety performance of vehicles and which compel and encourage the OEM to dedicate in providing better protections not only to occupants but also vulnerable road users. As a reward the ratings of top vehicles will be published, which is good advertisement. It is reported that vehicles of 5 star in NCAP will have 20% more than that of vehicles with 4 star.

In 2012, IIHS in USA has released a very aggressive impacting scenario, Small Overlap, SOL[1]. The vehicle is accelerated to 40 MPH and impacts on a rigid barrier with 25% overlap, shown as figure 1.

It is totally different from the traditional frontal full width rigid wall impact and frontal offset 40% overlap barrier impact. Because that most of the vehicle designed according to the traditional impacting scenarios does neither have enough structure to consume energy nor have strong enough carbine cage to retain the loading from the rigid barrier, shown as figure 2. As a disaster, most of vehicles including top brands, such as Audi, Benz, BMW, VW, Toyota and etc., did not have a good result for SOL. To rebuild the confidence of consumers to the brands, it is must be done that their vehicle achieves a good rating or acceptable rating in SOL to have a place in IIHS as models of TSP or TSP+.

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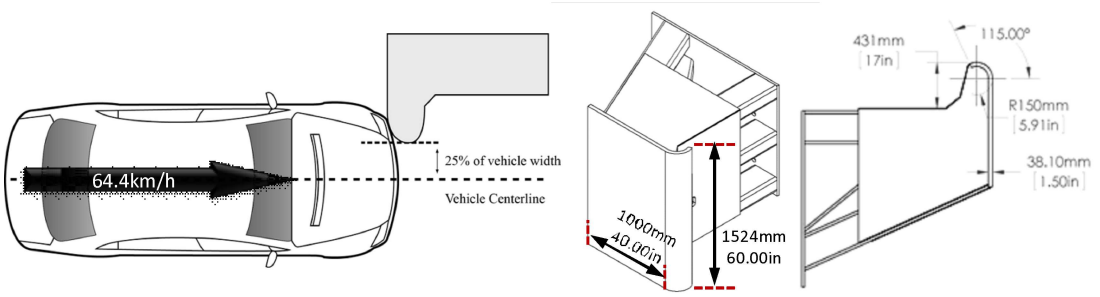


Figure 1. Impacting scenario of small Overlap

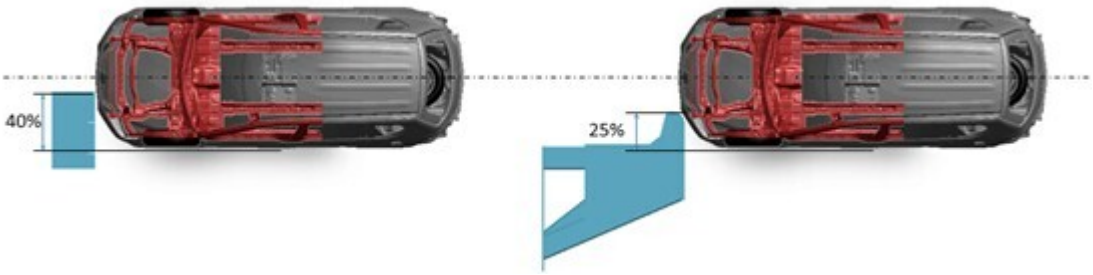


Figure 2. Vehicle Structure Overlapping with Barrier

2 Current Status and Engineering Approach

In 2012, IIHS released the first group of small overlap results in 2012, only 3 out of 33 were assessed as 'Good'. It leaded overwhelming pressure on OEMs. The safety performance of vehicles has been doubted a lot. Some of the OEMs started to complain the scenario is too aggressive and in-repeatable [2].

In 2013, the ratings of SOL are improved for most of the vehicle. Within 2014, 48 vehicles, including 9 vehicles for 2015, sold in USA could succeed 'Good' or no less than 'Acceptable' and ranked as TPS or TPS+, shown as figure 3[3].

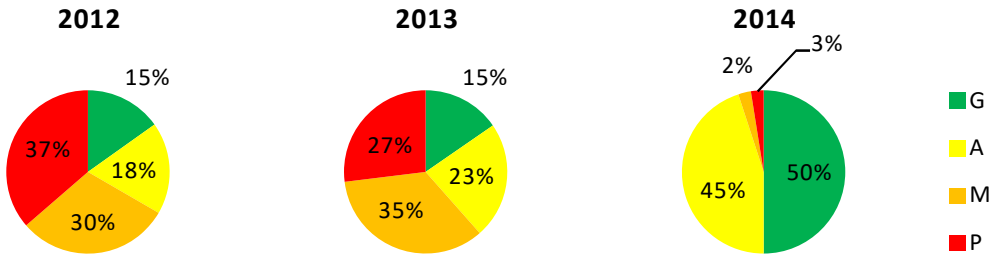


Figure 3. Small Overlap Rating Improvements by Years
(G-Good, A-Acceptable, M-Marginal, P-Poor)

After 2 years dedication work, a part of the OEMs have raped meaningful results. However, 48 vehicles ranking in TSP/TSP+ in 2014 and 2015 is about 40% of the number of TSP/TSP+ in 2013, 120 vehicles. There is a long and difficulty way for the rest vehicles to overcome.

2.1 Phenomena Observed in the released results

All the happiness is similar and the painfulness is different from each other.

According to results of small overlap in 2012, Honda Fit has the wheel disconnected from the vehicle body, which is very stiff and pushes the rocker and A-pillar deforming. It become much worse in the case of Hyundai Tucson, Toyota Camry, Honda Pilot and etc., shown as figure 4. However all of above ranked in TSP in 2012.

It can be summarized for the vehicle earned 'P' in SOL, which is called Category-A, that:

a) The wheel is attached or is not designed purposely to be disconnected from vehicle body the during the impact.
b) The rim of wheel remain undeforming, rupture or fly off the vehicle body, which will can absorb energy and reduce the loading to A-pillar and rocker.
c) The carbine of vehicle should be strong enough to minimize the deformation of vehicle body.
d) To earn 'G' as overall assessment, 'G' or 'A' for structure assessment is the precondition.

Honda Fit	BMW 3 Series	Hyundai Tucson	Toyota Camry	Honda Pilot
2012 'P'	2012 'M'	2012 'P'	2012 'P'	2012 'P'

Figure 4. Phenomena observed in vehicles with 'G' for SOL
(All the wheels disconnected with vehicle body, even rim ruptured)

According to latest results of 2014, very similar phenomena can be observed that the wheel on strut side of all vehicles have been disconnected from vehicle body and even some rim of them ruptured during the severe impact, Acura MDX, BMW 2 Series, Chevrolet Malibu for instance, shown as figure 5.

Acura MDX	BMW 2 Series	Chevrolet Malibu	Mini Cooper Countryman	Volvo XC60
2014 'G'	2014 'G'	2014 'G'	2014 'G'	2014 'G'

Figure 5. Phenomena observed in vehicles with 'G' for SOL
(All the wheels disconnected with vehicle body, even rim ruptured)

It can be summarized for the vehicle earned 'G' in SOL, which can be called Category-B, that:

e) The wheel can be removed off from the vehicle body during the impact.
f) The rim of wheel can deform, rupture or fly off the vehicle body, which will can absorb energy and reduce the loading to A-pillar and rocker.
g) The carbine of vehicle should be strong enough to minimize the deformation of vehicle body.
h) To earn 'G' as overall assessment, 'G' or 'A' for structure assessment is the precondition.

2.2 Theoretically Analysis

Kapil Butala and etc. studied the occupant injuries due to different categories of vehicle pulse based on reasonably correlated MADYMO models, shown as figure 5[4]. They concluded that the category 2 is more friendly to occupants: HIC15 50% reduced, Chest Deflection 15% reduced.

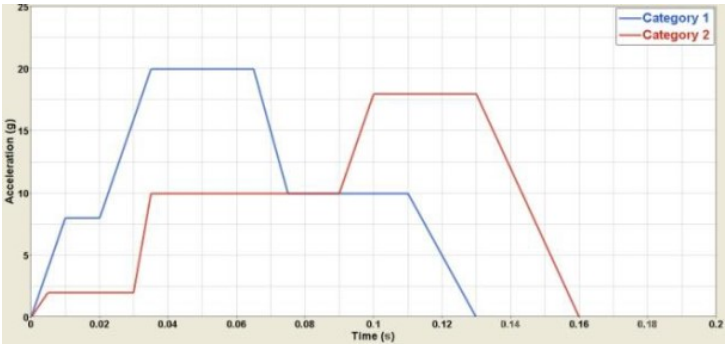


Figure 6. Simplified Acceleration versus Time Data based on Vehicle Categories[4]

Normally, the wheel rim of SUV is about 500mm. Considering the rotation and deformation, the undeformed wheel rim will take space about 450mm. Comparing with Category-A, Category-B will have additional 350mm deformation space, which result in a quite different pulse of vehicle for Category-A from that of Category-B theoretically, as shown in figure-7, if the same kinetic energy is dissipated by structural deformation. The pulse of Category-B will be much better than that of Category-A regarding to occupants protection. It will benefit the vehicle better performance in SOL wholly.

Simply, the loading to side structure will be reduced dramatically, about 40% reduced. This results in a complete different approach to earn 'G' in terms of structure performance: without weight penalty, the vehicle performs perfectly by designing realistic failure of knuckle assemble, which allows the wheel flying off.

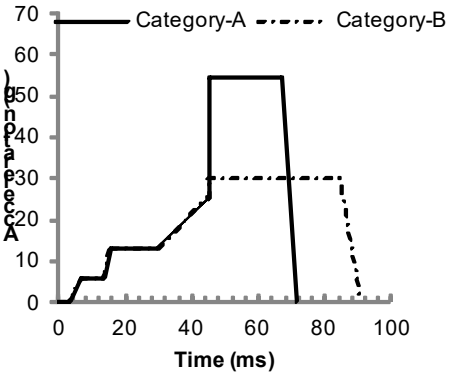


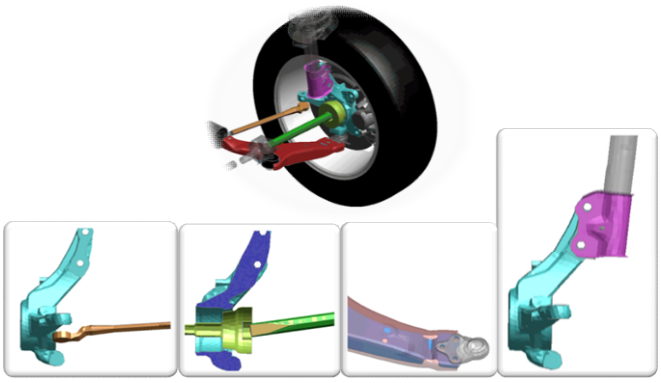
Figure 7. Vehicle impacting pulse due to failure of wheel knuckle assembly
(Category-A: vehicles without failure design; Category-B: vehicles with good failure design)

3 Engineering Approach

Based on above analysis, a SUV is designed in purpose of failure for wheel flying off from vehicle body to minimize the loading to side structure of vehicle, having a better performance and earning overall 'Good' assessment in SOL definitely.

3.1 Failures of Connections of Frontal Wheel to Knuckle Assembly

For common passenger vehicles, the frontal wheels are linked and attached to vehicle body by several connections: wheel to knuckle, knuckle to steering bar, knuckle to damping strut, knuckle to transmission shaft, and knuckle to swing bar, examples shown as figure 8.



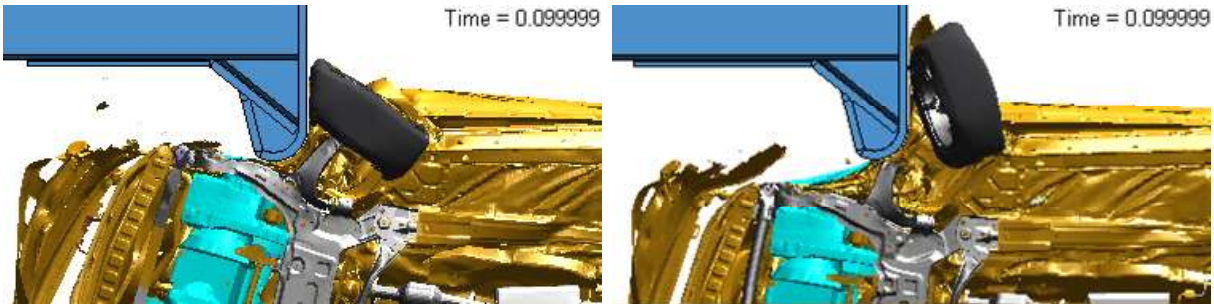
Knuckle to Steering bar | Knuckle to transmission shaft | Knuckle to Swing Bar | Knuckle to Strut

Figure 8. Connections of frontal wheels to vehicle body

If all of above connections fail or rupture during the impact, the wheel will fly off the vehicle body. Knuckle to steering bar is connected with a sphere joint, which can be disconnected if the loading to above the permit load, so does the connection between knuckle to transmission shaft and that of swing bar to knuckle. The connection of knuckle to strut may fail due to rupture of bolts or the damping bar dragged out of the sleeve, when the barrier push the tyre away from the vehicle body. In addition, Wågström studied oblique car-to-car impact by LS-Dyna Simulation in 2012[5]. The wheel rim is modeled with failure material, the tyre has ventilation and separation capabilities and the bushing is modeld with solid rubber elements representing the real structure to predict the response more accurately. Due to lacking the testing data of the connections, arbitrary time-dependent failures are set in the model.

3.2 Vehicle Response and Performance

The SUV studied has a complete and advanced structure in terms of safety. The fine designed body can earn 'Marginal' of structure assessment according the rating protocol of small overlap[6], which means body frame is advanced. With the state-of-art simulation technology, the failure of wheel connections is integrated to vehicle model successfully and the wheel can fly off from the vehicle body, shown as figure 9. The assessment of structure performance is upgraded from 'M' to 'G', shown as figure 10.



a) Without failure of wheel assembly **a) With failure of wheel assembly**

Figure 9. Comparison of vehicle deformation due to failure of wheel

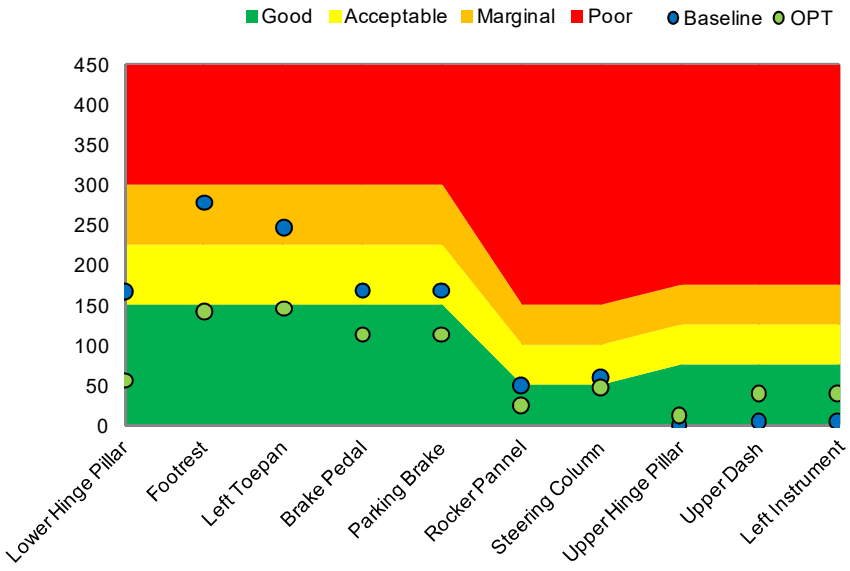
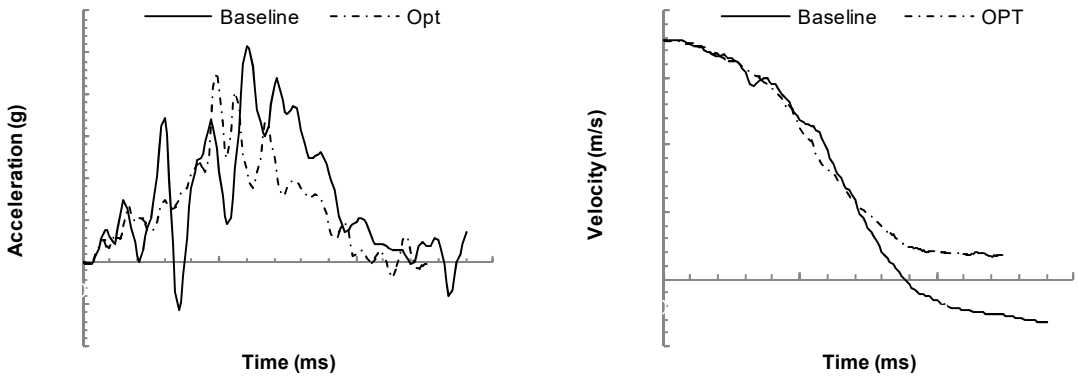


Figure 10. Comparison of structure assessment due to failure of wheel

The vehicle pulse become friendlier indeed, which has the similar trend as the prediction of theoretically analysis. Although the peak of the pulse is not improved a lot, there is some residual velocity, which means the vehicle can pass the barrier by after the impact, shown as figure 11. This lead to the total energy dissipated by vehicle body reduced by 6% and the work done by the barrier is reduced by 12%, which decrease the demand of the side structure of vehicle body.

Table 1. Comparison of Structure assessment of Some SUV due to Failure

Cases	Final Vx	Final Vy	Final KE -X	Final KE -Y	Energy Dissipated	Δ Momentum
	m/s	m/s	J	J	J	kg/m/s
Baseline	-3.17	3.23	10035	10403	299542	35.66
OPT	1.72	5.89	2947	34687	282346	20.56
Δ%	-154%	83%	-71%	233%	-6%	-42%



a) Vehicle deceleration vs. time

b) Vehicle velocity vs. time

Figure 11. Comparison of vehicle response due to failure of wheel

Without enhancing the vehicle body by adding reinforcement, increasing the gauge or upgrading material grades, the vehicle body can earn 'Good' assessment of structure only by considering the failure of the wheel connections, which contribute to weight reduction and worth of the full vehicle.

4 Discussions

Small overlap is a common accident scenario, which may happen by 24% in American [7], 25% in Germany [8]. Within domestic, although it is not reported officially. According to fatalities reported by WHO[9], estimated death rate of per million population is about 205 in traffic accidents. If the domestic frequency of SOL in accidents is assumed as 25%, it is estimated that 51 people per million populations will die due to small overlap in real accidents.

That is part of reason why Domestic authors investigated in SOL[10] and seek solution for full vehicle development recently[11][12] and got prepared for it.

It is can be foreseen that related regulation, standards or protocols would be released in the near future in China, considering the benefits to the consumers and harmonies of societies.

Hence, the key to vehicle structure performance for SOL will benefit the rest assessment of SOL in default, Injuries Criteria and Restraints and Dummy Kinematics. According to results released by IIHS, the vehicle having 'A' or 'G' of structure assessment will probably has 'A' or 'G' of overall assessment in 95%, 3 out of 71 vehicles, shown as figure 12.

However, it is reminded that the restraints system for SOL should have large Curtain Airbag, which interact with Driver Airbag and stably protect the head from impacting to the hard component in cabinet [11].

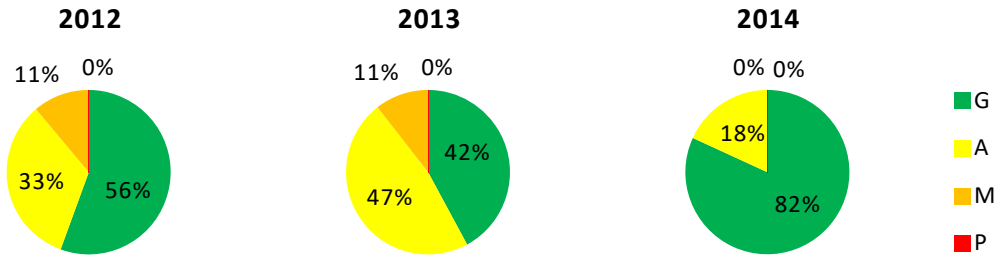


Figure 12. Vehicle rating for SOL with 'A' or 'G' of structure assessment

5 Conclusions

Small overlap is not only common (25%) in accidents but also fatal. The scenario promoted by IIHS has lead the requirement and demands of passenger vehicles for it. Although, most of traditional vehicles can not comply with it and failed to achieve a 'Good' rating. So far, it can be observed that some of the OEMs have done their best according to current results released by IIHS. There is a easier way to survived in small overlap:

1. Vehicle is designed with failure of knuckle assembly to vehicle body in purpose.
2. The side structure should be stiff enough to maintain the compartment deforming as little as possible.
3. The curtain should be large and stiff enough to interact with driver airbag and providing good protection to the head.

There is a day, when domestic vehicles rank top place of vehicle safety.

Acknowledgement

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