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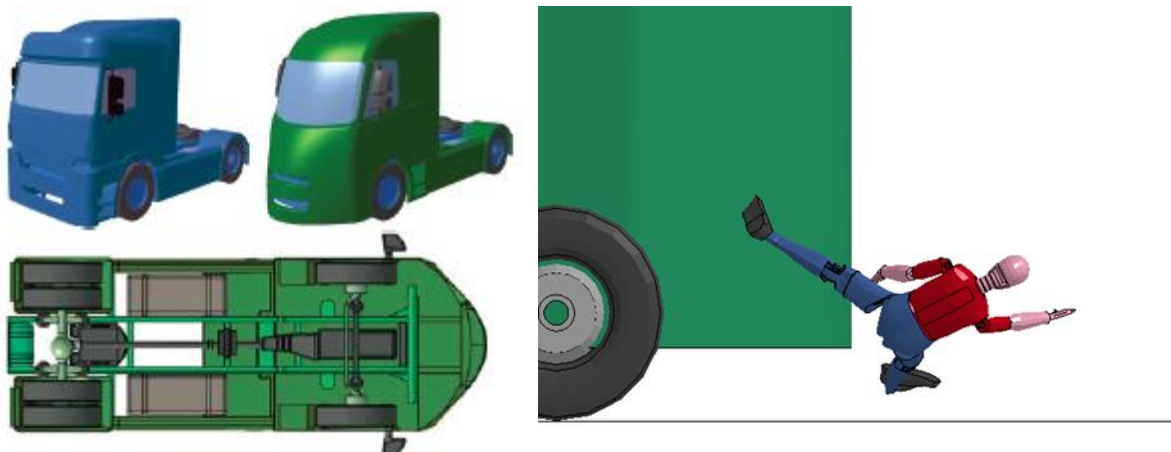


DRAFT PROJECT REPORT RR2018_003

Safer Aerodynamic Trucks

Assessing the potential for a geometric envelope to be used in length regulations: phase 2

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1 Introduction

Directive 96/53/EC, as amended by Directive (EU)2015/719, will permit HGVs to be longer than the length prescribed by that regulation, provided certain safety & environmental conditions are met. The Commission is now obliged to amend the regulatory requirements contained within the European Whole Vehicle Type Approval system, to ensure that cab elongation is permitted within type approval while also ensuring that suitable technical criteria are used to ensure the conditions around safety and environmental approval are met.

This task is more complex than it appears, mainly because Directive 96/53/EC applies length limits to individual goods vehicles but also to different types of vehicle and trailer combination in use. Type Approval by its fundamental nature is only applied to individual vehicles or trailers in isolation, and not to vehicle combinations. Some of the conditions involved that are easy to apply to combinations in use are not easy to apply at type approval to a vehicle that may or may not tow a trailer in service.

Aerodynamics is one measure where ideally performance would be measured in a vehicle combination. However, to do this at type approval would require the use of one or more standard trailers that may or may not reflect the actual use in service. As an alternative, it has been proposed that a vehicle will be 'deemed to comply' with the condition of improved aerodynamic performance, if its frontal shape falls within a geometric envelope that research has shown should result in improved aerodynamics.

Transport & Environment commissioned Apollo Vehicle Safety & GRM Consulting to investigate whether the same approach could be used to demonstrate compliance with the relevant conditions for improving safety. The work has involved computer simulation of the effect of different shaped HGV fronts on pedestrian impact kinematics and the direct vision provided to the driver of pedestrians in close proximity to the front of the vehicle. The shapes studied in the first phase of this work were found to carry safety risks that suggested that overall a vehicle minimally complying with that shape may present a greater risk to pedestrians than a standard baseline vehicle. A second phase of work was, therefore, commissioned that studied different geometries and material stiffnesses that would mitigate those risks and result in an enhanced set of envelope requirements that would increase the probability that a vehicle complying with the requirements would present a lower risk to pedestrians than a standard baseline vehicle.

This report briefly summarises the findings of the first phase of research and describes the second phase in full.

2 Methods

2.1 Phase 1

In phase 1 a baseline truck model (see appendix A) was created in a finite element simulation environment and this was run through simulations of a variety of pedestrian collisions covering different vehicle and pedestrian speeds, and different impact locations across the front of the vehicle. In addition to this, a parametric study was undertaken for different basic envelope shapes, independently varying plan view curvature of the front and rake angle of the front, relative to vertical. The values used were compared to existing concept vehicles, see for example Figure 1, below.

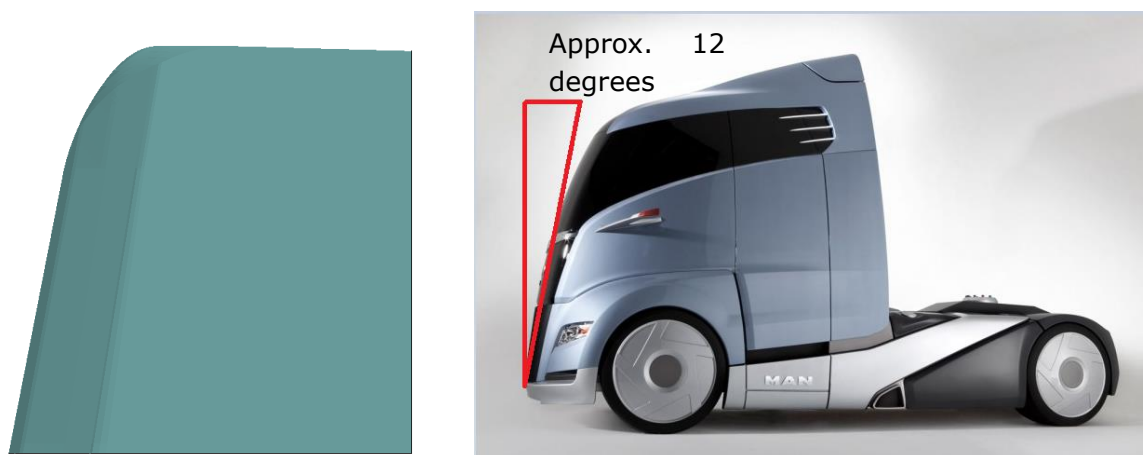


Figure 1: Example of modelled rake geometry based on existing concept vehicles.

The same collision situations were simulated for each geometric combination. The results were expressed in terms of a Head injury Criterion (HIC value) in the primary impact with the vehicle, expressed relative to the HIC observed in the identical baseline model impact, a second HIC value representing collision with the ground and a lateral distance that the shaping moved the pedestrian out of the path of the vehicle (to reduce the chances of subsequent runover).

In addition to this, some simple field-of-view evaluations were undertaken at different shape configurations, to assess the ability of a mid-sized driver to see vulnerable road users at the front of the vehicle.

2.2 Phase 2

In phase 2 a new shape concept was introduced, of a changing rearward rake above a certain height, as illustrated in Figure 2 below and referred to as a dual rake design.

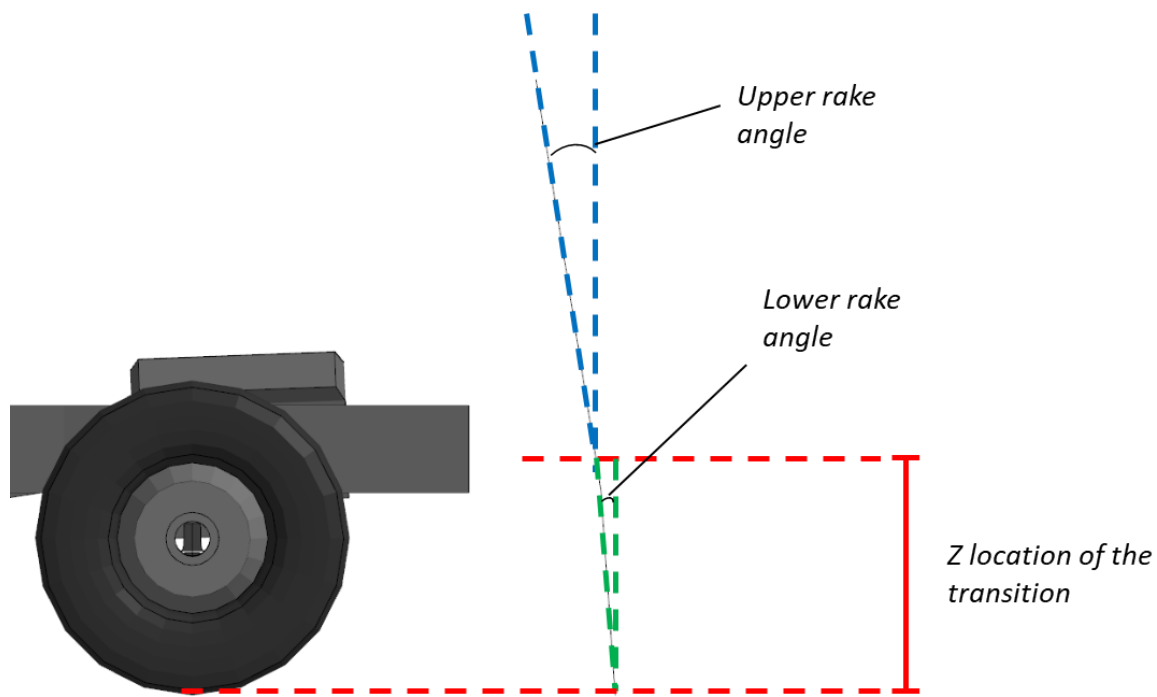


Figure 2: Illustration of a two-stage rearward rake in vertical cab profile

A further parametric study was undertaken to understand the effect of different upper and lower rake values as well as variation in the height from the ground of the transition between the two, based on the same output measures defined in the phase 1 work.

In addition to this, the parametric study was expanded to cover the use of rearward rake and plan view curvature in combination. In phase 1 plan view, curvature had been assessed with a vertical side profile and rearward raking in the side profile had been evaluated with a flat front in plan view.

The results from these additional parametric studies of geometry were then used to define a truck shape likely to offer good performance. Where areas of concern were still identified within this design, the effect of varying stiffness through either the use of friable windscreens in the head impact area or of controlled local deformation in panels (for example equivalent to a layer of expanded polypropylene foam) was assessed.

3 Results

3.1 Summary of Phase 1 results

In phase 1, the study was informed of evidence to show that as a minimum standard, an envelope requiring only modest plan view curvature at the outer edges of the vehicle combined with curvature at the roofline was sufficient to ensure aerodynamic benefit, even with a vertical side view profile. Details of this minimum standard envelope were as shown in Appendix B. The analysis of direct vision showed that assuming an unchanged position of the driver relative to the base of the windscreen and no change in the height of the base of the windscreen, then the changes to vision associated with a vehicle that is minimally compliant to this shape would have marginal changes in vision, associated with the slight plan view curvature and tapering at edges. To ensure improvements in direct vision with this shape would involve additional constraints which ideally would be based on a comprehensive direct vision standard but in the short term could involve some simpler constraints. Options included:

- a highly simplified direct vision requirement directly inserted into Regulation 1230/2012/EC. This could, for example, define a simple area in front of the vehicle that must be visible from a longer vehicle, that would not be visible from a standard reference;
- requiring improved indirect vision, which could be based on UNECE Regulation 46 with higher minimum standards;
- requiring blind spot information systems and/or collision warnings: requirements for blind spot information systems are close to completion and are expected to be adopted as a UNECE regulation. Enhanced cab designs could be required to meet a higher minimum standard.

It should be noted that the research found that the evidence on the effectiveness of mirrors was ambiguous and that there was evidence that direct vision was more effective. Evidence about information systems was new and emerging but early indications were that they could be effective, but much would depend on details of the implementation.

The findings with respect to pedestrian safety were complex. However, it was found that it is unlikely that, in isolation, the envelope developed as a minimum standard for aerodynamics would ensure any real improvement in pedestrian safety on an aggregate basis. Thus, for impacts to the main part of the front of a vehicle that just complied with this envelope, where the side view profile is vertical, at best there would be no change, and at worst the outcome could be worse because many existing vehicles do have some small element of rearward raking.

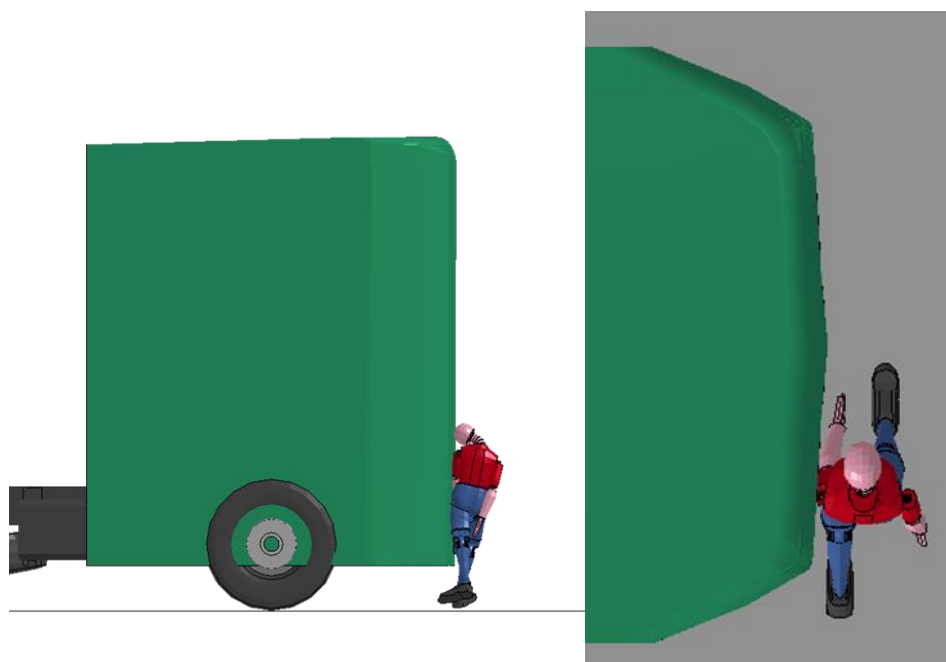


Figure 3: Side view and plan view of a vehicle minimally compliant with an envelope developed for aerodynamic benefit.

In plan view, the edges of the vehicle are tapered. Thus, in a small proportion of impacts that occur right at the edges of the vehicle, this would have some benefits in deflecting pedestrians to the side. However, in combination with the vertical front, this would be offset by a substantial increase in head injury risk in the primary impact with the vehicle. This increase arose because the plan view profile meant that the head contacted the vehicle before the shoulder such that the cushioning effect of the shoulder impact was removed.

Based on the parametric evaluations undertaken it was still expected that there would be an optimum shape within the minimum envelope that would improve the benefits and mitigate the areas of risk, such that the finding remained that there were potential benefits to increased length and curvature. It was hypothesised that slight changes to the minimum envelope might go a long way towards ensuring that those benefits could be captured while minimising the risks. It is these hypotheses that were tested in phase 2.

In addition to consideration of the safety elements, phase 1 considered how it could be guaranteed in type approval regulations that the available load length would not increase if new requirements allowed extended cabs. While straightforward for vehicle combinations, this was found to be problematic for rigid HGVs and it was found that it could only be defined in relation to a benchmark value for existing rigid trucks, which in reality may mean that some vehicles might gain a little and others lose a little. Options for how to define the benchmark were presented:

- Define max load length based on maximum or average available in current fleet: Simplest approach but hard to account for day/sleeper cab variations.
- Define max load length based on averages for different sub-types of vehicle (e.g. sleeper, day cab). Tighter control over load length but more complex
- Defining the maximum nominal length of the vehicle based on the distance between the accelerator heel point (AHP) and the rear of the vehicle. Likely to be a still tighter control on load length but a more abstract concept with possible constraints on direct vision in some design configurations.

3.2 Phase 2

3.2.1 *Head injury in collision with the ground*

With the benefit of an increased number of simulations in different conditions, it became apparent that the measure of head injury (HIC) in collision with the ground was highly variable. Looking at this more closely identified that very similar impacts could result in very different head injury criteria. The main dependency was in whether the head contacted the ground directly as the first impact, or as a secondary impact after other body parts had contacted the ground, softening the blow including cases where arms came between head and ground. A comparison is shown below for normalised HIC value and pedestrian motion in different conditions.



Figure 4: Pedestrian motion and HIC in ground impact for the dual rake cab with a transition height of 150mm, the baseline cab, a dual rake cab with a transition of 950mm and a single rake cab at 15 degrees.

Based only on HIC values from ground contact then the best cab is the dual rake with transition at 150mm with a HIC value one fifth of the baseline value. The same dual rake

cab but with a transition height of 950mm gives a HIC almost 18 times the value of baseline and 88 times the value of the same cab with a transition height of 150mm. However, when looking at the actual motion of the pedestrian, it is almost identical for both of the dual rake cabs in the early phases, with a neutral push forward resulting in them remaining relatively upright. The reason for the difference is that for the 950mm cab, the knees catch on the ground and rotate the upper body such that there is a direct head contact. For the 150mm cab, this does not happen, the pedestrian continues to fall sideways and his arm comes between the head and a contact with the ground.

It can be seen that the kinematics of the baseline vehicle and the 15 degree rake are much more substantially different. In the baseline vehicle, the pedestrian is more quickly pushed toward the ground but first directly onto its back, whereas in the 15 degree rake it is clearly thrown upwards slightly and strongly rotated around the centre of gravity such that it lands on its head from a greater height.

So, although the HIC value correctly identifies the undesirable kinematics of the 15 degree rake it does not really correlate with expectation based on the kinematics of the three more similar vehicles. Effectively, random small variations occurring a relatively long time after impact are having a very large effect on the outcome. In fact, it can be said that the baseline impact has somewhat of a 'lucky' fall, which means measurements compared to this baseline will appear disproportionately bad in many cases.

It is clear from the results that head impact with the ground can be more severe than head impact with the vehicle but that this is not always the case, depending very strongly on how the pedestrian falls to the ground. It is also clear that the shape of the front of a vehicle does affect the way that the pedestrian is pushed or falls to the ground at a high level. However, HIC measurements do not successfully isolate those variables so cannot be used as a reliable indicator of those changes. In the absence of a test/measurement that more reliably relates injury potential to the observed kinematics, it can only be said that design features that cause an increase in head height and/or strong rotation around the centre of gravity immediately after impact are likely to increase the chances of injury in ground contact and should be avoided. HIC values for ground contacts have not been reported in the subsequent analyses presented.

3.2.2 *The effect of dual rake design*

The parametric study was undertaken to assess the affect of using different upper and lower rake values and varying the height at which the transition between the two took place. The analysis of rake angles is presented below. It should be noted that while varying lower rake angle, the upper rake angle remained fixed at one angle (6 degrees) and when varying upper angle, the lower remained fixed at 4 degrees.

Table 1: The effect of upper and lower rake values (in isolation) on HIC in primary impact with the truck, relative to the baseline vehicle

Lower Rake (°)	HIC to Truck (Normalised)	Upper Rake (°)	HIC to Truck (Normalised)
1	0.73	3	0.75
2	0.73	4	0.89
3	0.74	5	0.86
4	0.74	6	0.74
5	0.71	7	0.86
6	0.68	8	0.62
7	0.69	9	0.58

It can be seen that all combinations of the dual rake profile considered reduced HIC compared to baseline (to within a range between 58% and 89%). Within the range tested, the findings were that the outcome was relatively insensitive to the lower angle but outcome improved with increasing upper rake angle. The modelling only extended as far as an upper rake of 9 degrees, but the theory should be that as long as the lower rake stays small further increases to upper rake should produce additional benefits for head injury in the primary collision without causing the adverse kinematic effect of being pushed upward and, therefore, having further to fall to the ground.

The results also showed that HIC was relatively insensitive to the height at which the transition (between the lower and upper rake) occurred, until the maximum height of 1350mm from the ground was reached. At this level, the transition coincided with the height of the pedestrian shoulder such that the impact became similar to that with a single uniform backward rake of lower value. That is, the benefit of the upper 6-degree rake was lost. These simulations were undertaken using a 50th percentile male pedestrian. When considering what transition heights should be allowed in regulation, it will be important to consider the equivalent shoulder height in relation to the proportion of the population that should benefit from the increased upper rake angle. For example, if the maximum transition height was 200mm less than the height of a 5th percentile female shoulder, then a much larger proportion of the population would benefit than it a value of 1150mm was chosen (200mm less than the 50th percentile shoulder).

The optimum rake transition point is discussed further below.

Table 2: The effect of dual rake transition height from ground on HIC in primary impact with the truck

Z –Height (mm)	HIC to Truck (Normalised)
150	0.73
350	0.71
550	0.75
750	0.74
950	0.76
1150	0.77
1350	0.93

3.2.3 Plan view curvature combined with rake

Phase 1 showed that with a vertical side view profile and a curved plan view profile, head injury in primary impact with the vehicle would be increased. The effect of plan view curvature was re-analysed with the dual rake side view profile of 4 degrees lower and 6 degrees upper angle with a transition at 750mm. The results are shown below.

Table 3: The effect of plan view curvature in combination with rearward rake on HIC in primary impact with the vehicle

Angle (°)	HIC to Truck (Normalised)
0	0.74
10	0.75
20	2.40
30	9.85
40	17.61
50	20.66
60	19.49

It can be seen that in combination with rearward rake, plan view curvature does not make HIC worse than the baseline vehicle until an angle of somewhere between 10 and 20

degrees is reached. With 10 degrees angle, a lateral displacement of the pedestrian away from the path of the vehicle of around 1.1m was achieved, such that some benefit of reduced run-over might still be expected. Much greater deflection potential exists at the higher plan view curve angles but with a consequent increase in initial head injury risk.

3.2.4 Design optimisation

An initial optimisation analysis was run using parametric results from both phase 1 and phase 2. The aim of this optimisation was to assess whether it remained feasible to produce beneficial designs within the constraints of a regulatory envelope of permitted geometries. The analysis suggested use of the dual rake approach with an upper rake angle of 9 degrees and a lower angle of 6 degrees. The height of the transition was not particularly significant as long as it is below a level that influences head motion and was selected as 1m from the ground.

In terms of plan view curvature, it was clear that there are aerodynamic benefits to a substantial curvature and this also has benefits in the prevention of runover. However, it is also clear that substantial curvatures can make initial head impacts worse. Thus, a compromise was selected where the upper portion of the cab was tapered back at around 60 degrees but a wheel arch structure was developed such that the plan view curvature was less at a lower height from the ground. The resulting cab profile is as shown in Figure 5, below.

Analysing the impact performance of this design showed that for impacts all across the nearside then there was a tendency to deflect the pedestrian to the side, reducing the risks of runover. Where impacts occurred in the area of the wheel arch, then the HIC value on primary impact was reduced almost to two thirds of the value for the equivalent location on the baseline vehicle (0.7). In the centre of the vehicle, the HIC value was about the same as for the baseline vehicle, despite the 17.5-degree plan view curve back. However, at a very defined impact location on the area where the upper cab transitions to the much larger plan view curvature rear and the lower cab becomes the wheel arch, then the head impact with the cab could be made considerably worse (11.6).

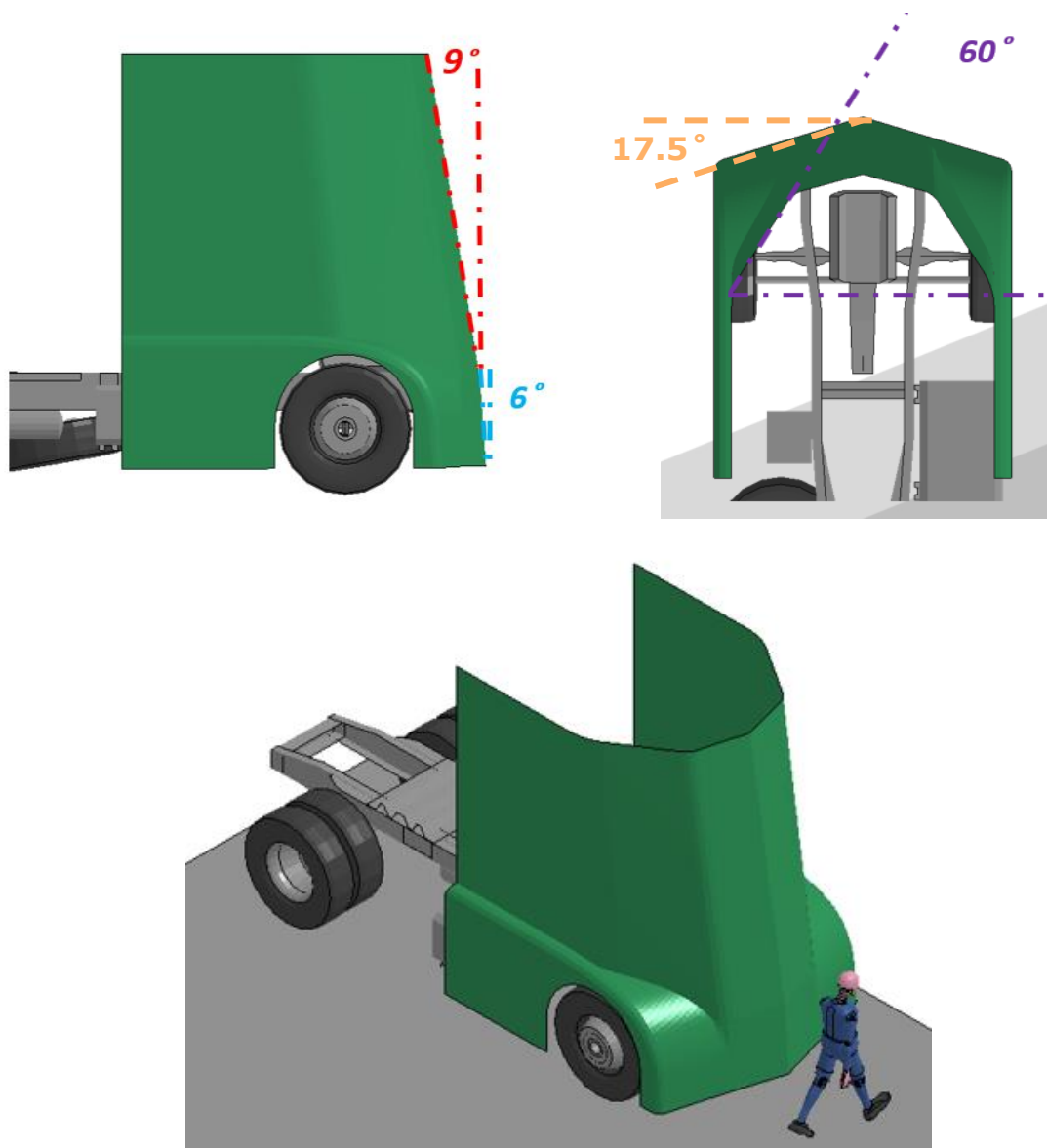


Figure 5: Design outcome of an initial optimisation analysis

3.2.5 Mitigation of risks

In the areas where increased risks were observed, an initial examination of the potential of varying local stiffness was undertaken. Two approaches were studied, one based on assuming the head impact zone might become part of a windscreen with good protection properties and one based on typical properties for a layer of polypropylene foam, as illustrated in Figure 6, below

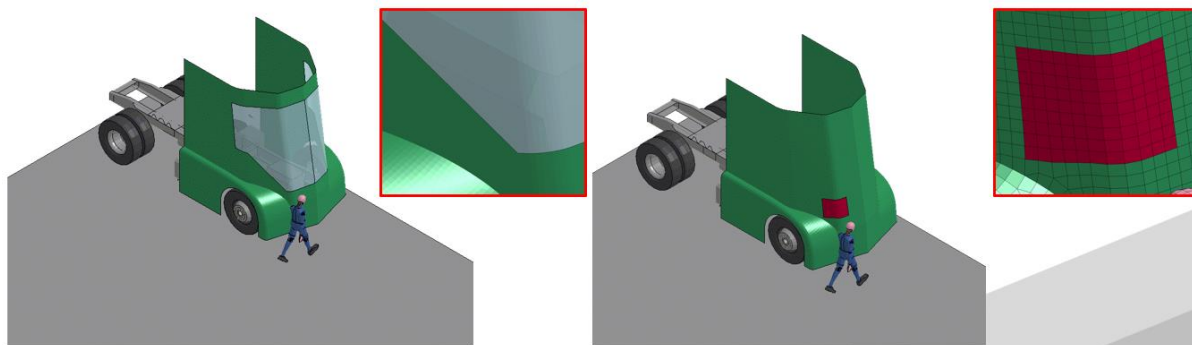


Figure 6: Examples¹ of possible local stiffness mitigation measures for high risk areas

When stiffness values are identical to the baseline vehicle, then the head injury risk (HIC) for an impact in this specific transition area was 11 times that of the baseline vehicle. The addition of these mitigations reduces that increase to 1.06 to 1.28 times the baseline vehicle.

If the stiffness is reduced over a more generalised area, the benefits can potentially be lost or reversed in some circumstances because the contact with the shoulder also deforms the material moving the head closer to contact with the structure. Effectively this means the benefit of the rearward rake can be lost.

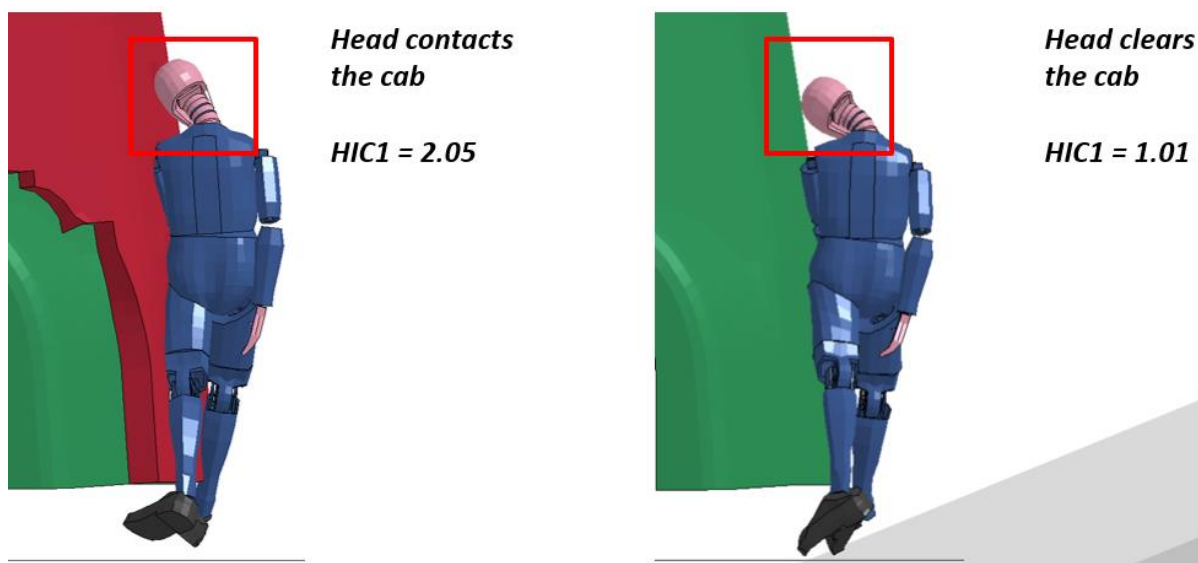


Figure 7: Effect of generalised stiffness reduction

3.2.6 Summary of pedestrian impact performance.

Based on the combined results from phase one and two, then a vehicle profile with a dual rake profile in side view would reduce injury compared to one with a vertical profile. The magnitude of the upper rake and keeping the transition between upper and lower rakes

¹ These are presented as examples only, it is understood that other constraints such as cab strength regulation (R29) may limit the suitability of some solutions for some vehicles, depending on design. The principle assessed is to permit small quantities of local deformation under head impact loads.

at a height significantly lower than the pedestrian's shoulder height would be the key parameters.

Plan view curvature offers a reduction in runover risk that increases with increasing angle up to around 45 degrees. Combining rearward rake with plan view curvature mitigates the adverse effects on HIC in initial truck impact found for plan view curvature in combination with a vertical profile. However, HIC reductions are only observed at angles of up to between 10 and 20 degrees. More curved profiles then increase HIC risk in initial impacts with the truck. Where larger curved profiles are desirable for other properties such as aerodynamics it is possible to mitigate the risks further by optimising the design such that the plan view curvature is less at a low level than at a high level (e.g. use of wheel arches with a narrower cab) but this can leave very localised areas of increased risk. These localised risks can be mitigated by localised reduction of stiffness. A more generalised reduction of stiffness could potentially have adverse effects in some specific circumstances.

4 Proposals for a regulatory envelope

Combined with phase 1 results, then the analyses suggest that a vehicle minimally complying with a dual rake envelope would be very likely to provide improved direct vision and to have net overall benefits to pedestrian impact safety. The results lead to an initial proposal for a suitable outer envelope for controlling vision and safety as shown below.

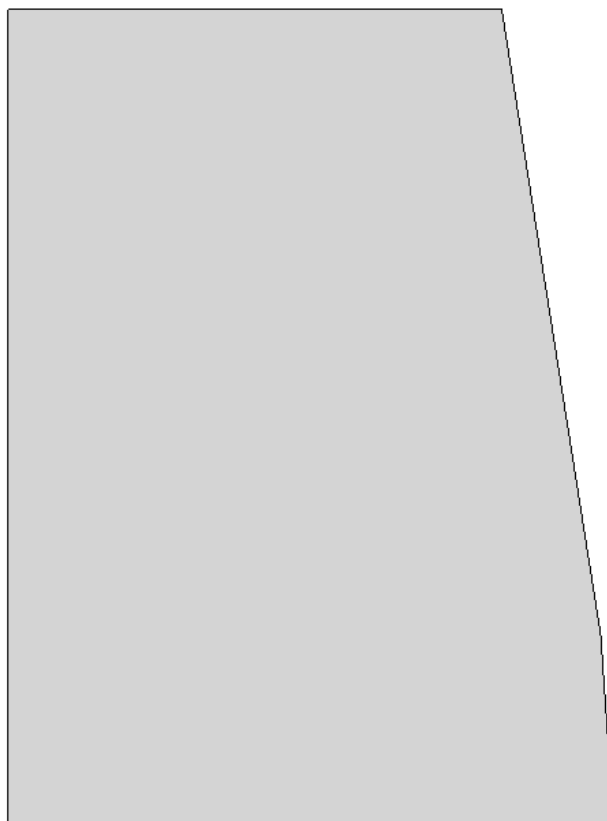


Figure 8: Side view profile of an enhanced geometric envelope to control the frontal shape of enhanced cab designs

The safety performance of this shape is only slightly sensitive to the lower rake angle. For best results it should be greater than 4 degrees but it would be very nearly as effective if it remained vertical (0 degrees).

There is more sensitivity to the upper rake angle: benefit is observed even at 3 degrees but 9 degrees is better.

The height of the transition between the two is not important until it gets close to the shoulder height of the pedestrian that is struck (1350mm in the case of the 50th percentile male in walking pose used in this analysis). It is likely that an upper limit of 1m would ensure benefits across a much wider proportion of the population: an analysis of population and casualty data may provide an optimum value.

Based on the findings above, the commission will have options for which geometries to select based on the level of casualty effectiveness they wish to capture. Two viable options are presented below, based on the baseline geometry used in the parametric analysis and the geometry that resulted from the initial optimisation process.

Table 4: Two viable options for ensuring pedestrian safety benefits are captured by an envelope approach to regulation.

Parameter	Baseline	Optimised
Min Lower rake angle	0 degrees	6 degrees
Min Upper rake angle	6 degrees	9 degrees
Max Transition height	1m	1m

Nominally, the height of the envelope should be 4m tall, equivalent to the maximum permitted height for cross border EU travel. However, as drawn, the envelope continues to rake back up the maximum height. This has no safety effect at heights above that of the tallest pedestrians in walking stance. Thus, the application of the safety envelope could be limited to structures at a height of less than 2m from the ground i.e. structures above that height are permitted to fall outside of the envelope.

Plan view curvature can have both advantages and disadvantages and finding the optimum balance will require manufacturers to undertake sophisticated optimisation programmes considering rake and stiffness as well as performance in other areas such as manoeuvrability, aerodynamics, field of view and occupant protection (cab strength). In an outer envelope aimed at safety improvements, it would be beneficial to continue to allow conditions that involve less complexity. Thus, in plan view, a simple rectangle of width 2.55m would be an acceptable approach that allowed the benefits of the side view rake to be observed in impacts across the front of the vehicle without the complexity of plan view curvature.

However, even with modest length increases it could be difficult to comply with manoeuvrability requirements without some chamfering or curving of the front corners of the vehicle and this has been identified as an important part of the aerodynamics envelope. Incorporating plan view curvature at the edges would suggest an envelope in plan view as shown below.

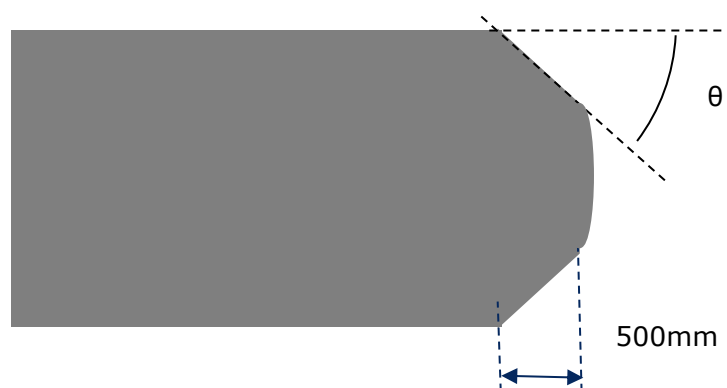


Figure 9: Plan view profile of an enhanced geometric envelope to control the frontal shape of enhanced cab designs

In this case, the maximum value of θ could be taken to be the value at which the HIC value in primary impact with the vehicle equals the baseline vehicle, such that combined with the vertical rake and the deflection to the side there remains an unambiguous safety benefit. Benefits for HIC were found at an angle of 10 degrees and disbenefits at 20

degrees. The initial optimisation used process used an angle of 17.5 degrees with good overall results.

Based on the results of the study, then a real vehicle just complying with these geometries as outer envelopes would be expected to offer small benefits in terms of direct vision and more significant benefits in terms of pedestrian impact kinematics. Designing within these envelopes, it should be possible to obtain more significant safety benefits and a rigorous optimisation process would be expected to produce a substantial net benefit and minimise the specific risks that can occur in certain circumstances. However, it should be noted that the envelope approach in isolation cannot guarantee overall benefits for all designs within the envelope. There may exist hypothetical design shapes which are compliant but worse for safety. The only commercial factor that appears to have the potential to drive such designs would be aerodynamics, if for example highly streamlined cabs without a dual rake approach dramatically improved fuel consumption. The key point is that vision and pedestrian safety performance must be a central part of the design process. Also, it may be possible to design vehicles that are safer than baseline in terms of vision or pedestrian safety performance that do not comply with the envelope geometry proposed.

Guaranteeing safety performance across all vehicle designs would require the development of proper robust standards and tests for direct vision and pedestrian protection. This is feasible but would take significant time.

Similarly, extending the length of the cab should increase the volume of space inside it which would be expected to offer opportunities to improve the design for driver comfort. However, it does not guarantee it. Where optimised designs employ a narrower upper portion of the cab for the benefit of aerodynamics, this could potentially reduce the available driver space.

Aside from the analysis for rigid trucks undertaken for phase 1, and summarised earlier, the work did not consider how load length can be constrained in order to be considered not to increase the loading capacity relative to a vehicle that does not take advantage of the ability to extend the cab.

Finally, in terms of front under-run protection, FUP-specific regulatory change is not thought necessary for shorter elongations but will likely need to follow revision of 1230/2012 for vehicle-makers to fully capture the benefits of the reform.

5 Conclusions

- 1) Simulations have confirmed that curved profiles generally considered more aerodynamic can have benefits for pedestrian impact kinematics and direct vision. In particular, a raked back design (in side view profile) can be beneficial and a dual rake side profile helps allow protection to the head in the primary impact with the vehicle without pushing the pedestrian into the air, which may potentially make the secondary impact with the road surface worse.
- 2) Tapering (in plan view) the front corners of the vehicle has advantages for deflection of vulnerable road users but has disadvantages for severity of initial head impacts if the vehicle front is vertical in side view. Where the front is also raked backwards, then this adverse effect is mitigated such that at taper angles of up to between 10 and 20 degrees, the initial head impact can be less than or equal to the baseline vehicle.
- 3) Analysis shows that a dual rake design would be expected to slightly improve the direct vision to the front of an HGV, provided all else (e.g. height of the lower edge of window, seat position relative to window etc) remains equal.
- 4) Thus, it can be seen that a vehicle minimally compliant with the enhanced dual rake envelope approach to regulating the length of goods vehicles would be expected to offer safety benefits the size of which would depend on the exact geometries selected, for example:

Parameter	Baseline	Optimised
Lower rake angle	0 degrees	6 degrees
Upper rake angle	6 degrees	9 degrees
Transition height	1m	1m
Plan view taper angle	10 degrees	17.5 degrees

- 5) The benefits expected are relatively insensitive to the rake angle at the low heights and the height at which the transition to the steeper rake begins, provided it is significantly lower than the shoulder height of the pedestrian struck. Thus, there can be significant flexibility in the definition of the exact values specified in the regulation. Small net benefits would be expected with zero lower rake, a transition height of 1m and an upper rake of 3 degrees. Benefits tend to increase mainly with increasing upper rake.
- 6) Additional benefits could be achieved using greater values of rake and tapering/plan view curvature within such an envelope but does carry risks of increasing injury probability in certain circumstances. A rigorous optimisation process would be expected to produce a substantial net benefit and minimise the specific risks. However, it should be noted that the envelope approach in isolation cannot guarantee overall benefits for all designs within the envelope. There may exist hypothetical design shapes which are compliant but worse for safety. The commercial driver for such design is likely limited to aerodynamics but this possibility shows that safety must be a central part of the design optimisation process.

- 7) Ensuring that 12m rigid vehicles with longer cabs do not benefit from increased load capacity will be complex and will involve the derivation of some sort of benchmark from the existing fleet. It is thought that the closest approximation could be derived by controlling the longitudinal distance of the Accelerator Heel Point to the rear of the vehicle. However, this does place a constraint on driver positioning within any extended cabin and, as such, could have an adverse effect on vision unless implemented in partnership with a specific requirement for improved vision, not compliance with the envelope alone.

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Appendix A The baseline truck model

The baseline truck is illustrated and dimensioned in Figure 10, below

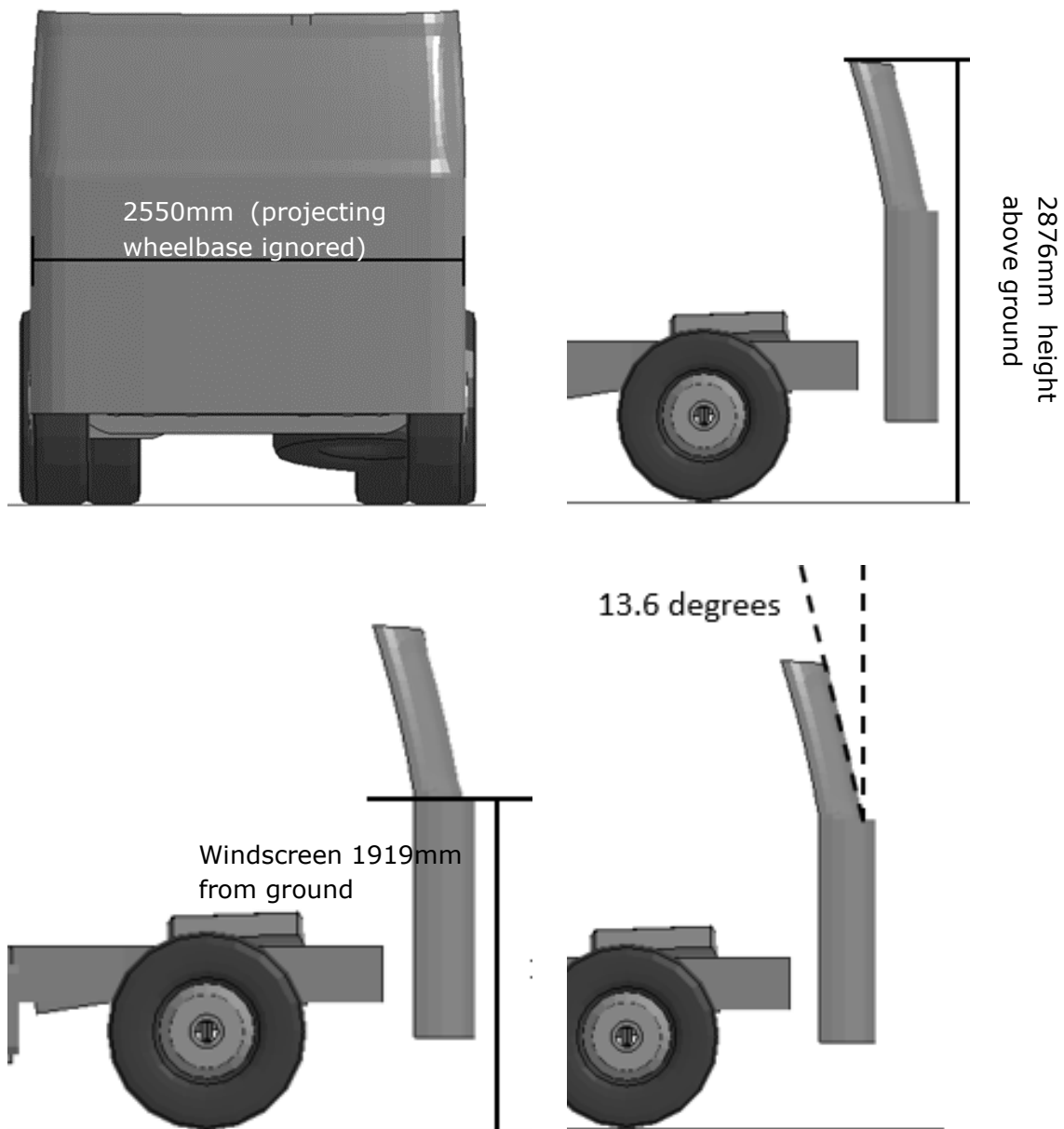
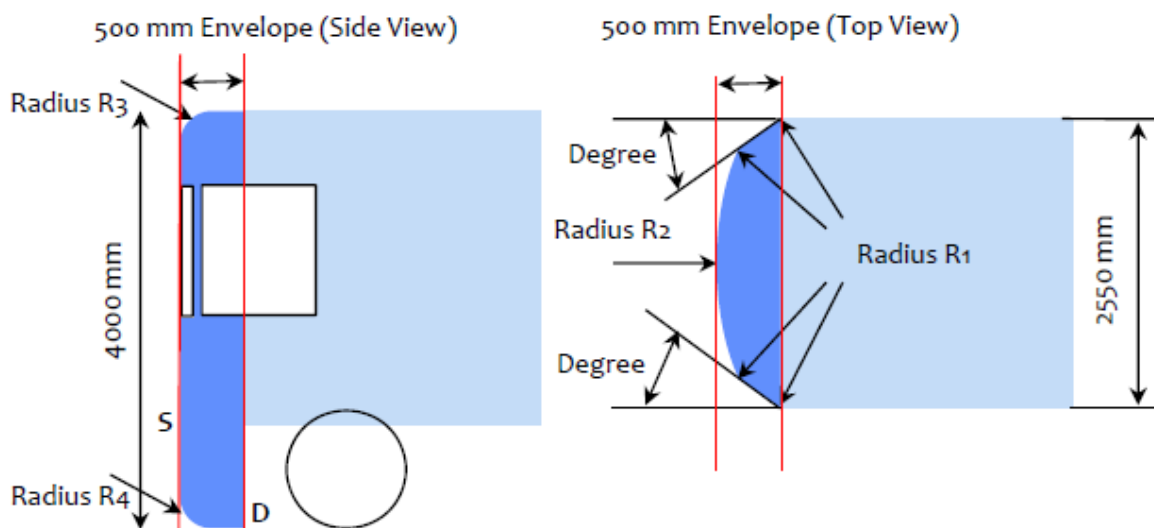


Figure 10: The baseline truck model

Appendix B Geometry of a minimum standard envelope created for aerodynamic benefit

Details of this envelope shape were provided to AVS/GRM and it is understood to be a minimum design considered to demonstrate significant aerodynamic benefits over a baseline vehicle. The details are shown in Figure 11, below



Criteria		Values
R1	radius to connect front to the sidewall (min)	100 mm
R2	radius of front area (max)	20 000 mm
R3	Radius to connect front with roof (min)	250 mm
R4	Radius to connect front to underbody (min)	No value
α	taper angle (degree in the picture)	20 degree
D	minimum distance of front respect the ground	0 mm
S	Front slope	0 degree

Figure 11: Details of the proposed envelope for aerodynamics