Attachment 38: Bus Front End Design – Minimum Geometric Requirements Guidance Notes

(Vulnerable Road User (VRU) Frontal Crashworthiness)

1 Introduction

Bus fronts have been identified as one of the key injury-causing contact areas of the vehicle in collisions between buses and Vulnerable Road Users (VRU). Therefore, all bus front ends are required to have a global geometric design that both improves protection for VRUs during the primary impact of a collision and reduce the risks of VRUs being run over subsequently.

As such, all [new] buses shall have a front end design that complies with the Vulnerable Road User (VRU) crashworthiness minimum bus front end geometry requirements for both vertical rake and wraparound windscreen curvature.

This document sets out the guidance notes related to the assessment of the global bus front end geometry and specifically, with respect to the minimum requirements contained in Section 4.6.1 of the Bus Vehicle Specification. These guidance notes are aimed at bus operators and OEMs as a practical guide for implementation of the requirements specified by the Bus Vehicle Specification.

These notes are for guidance only and are not legally binding. In all circumstances, the guidance provided by an OEM or system supplier shall take precedence, and these guidance notes are only for use in the absence of other information. These are not intended to be exhaustive, but to point the operators toward practical advice and questions to raise with OEMs/suppliers.

For full understanding of this Attachment it should be read in conjunction with the New Bus Specification, Section 4.6.1

2 Selection of buses/systems

From 2021 until 2024, all [new] buses shall have a front end geometry that complies with the minimum bus front end geometry requirements for both vertical rake angle and wraparound windscreen curvature. Therefore, selection can be any bus model or variant that is compliant with these specifications.

2.1 Intention of the requirements

The minimum bus front end geometry requirements intend to encourage bus front end designs that implement a wraparound windscreen design (as opposed to a box-fronted front end, where the A-pillars are located at the very front edges of the windscreen), as well as a positive vertical rake angle (i.e. the vertical angle).

It was found in research conducted on behalf of TfL that impacts against the more compliant wraparound windscreen material resulted in a considerable reduction in VRU injury risk, relative to impacts against the much stiffer A-pillar structures. This was coupled with a significant proportion of VRUs impacting the A-pillar region during collisions, particularly on the passenger side. Furthermore, run over risks were found to increase during collisions with bus front end designs that included a section with a negative vertical rake, due to the VRU essentially being pushed under the bus by these sections.

Of the bus model variants investigated, the wraparound windscreens with a radius of curvature of ~150 mm at the edge of the windscreen were found to be safer than traditional windscreen designs (where A-pillars are located at the front of the bus). As the structural stiffness of these wraparound sections are determined by the radius of curvature, a radius of curvature of less than 150 mm at the edges of the wraparound windscreen is considered undesirable, as this stiffens the structure and causes greater harm to the VRU if impacted. Similarly, negative vertical rake angles are considered undesirable, due to the increased run over risks that they present to VRUs.

These requirements therefore seek to promote the deployment of [new] buses into the TfL network with wraparound windscreen designs and positive vertical rakes, as these are intrinsically safer than traditional windscreen designs. To control for the stiffness of wraparound windscreens, these requirements ensure a minimum permissible radius of curvature of 150 mm between 0.75-2.0 m. To ensure that no bus results in a design that pushed VRUs under the bus, these requirements ensure minimum vertical rake angles of at least 1° between 0.75-1.2 m and 4° between 1.2-2.0 m.

2.2 Interpreting the requirements and selecting the most effective way to fulfil them

The minimum requirements are intended to dictate a progressive surface geometry for the bus front end to bring about improvements in vulnerable road user protection. It is expected that the surface is broadly continuous in this regard. However, it is also recognised that necessary features are incorporated in the bus front end for functional reasons and styling. Experience from the car industry suggests that small projections and protrusions can be used to provide localised areas of angled surfaces. The most effective vulnerable road user protection will be realised if the geometry requirements are adopted generally, the greater the size of the areas presenting that angle then the more effective the measure will be.

2.3 Compliance checks

It is expected that compliant vehicles may be selected from the current available TfL bus fleet. On consultation with OEMs, it was agreed that all current bus model variants with a wraparound windscreen design should have a radius of curvature and vertical rake that comply with these requirements.

Bus operators should ask to see documentary evidence of compliance with these requirements. Compliance may be established through either a CAD-based approach or physical testing. Whichever approach is adopted, a dossier of inspection points and measurements should be provided to assure compliance.

3 Training

3.1 For Test Services

The nature of verifying compliance with the requirements will depend on whether it is demonstrated through CAD or physical testing.

For CAD assessments, appropriate sections should be cut to demonstrate bus front end geometry in a way that can be visualised against the requirements. Any inspection should be facilitated by applying tangents or radii to the surface where the appropriate angles of rake or radius of curvature can be viewed. It should be possible for the inspection to identify the worst-case angle throughout the section.

For physical inspections, the vertical rake can be measured with an inclinometer. Here it should be noted that the footprint for these measurements should be 236 ± 5 mm x 236 ± 5 mm. This is to ensure that only the global geometric features of the bus are considered by these requirements and that smaller features are considered to not have a significant effect on the outcomes of VRU collisions. Test houses undertaking approval tests to UN Regulation No. 127 or UN Regulation GTR No. 9 will already possess the capability to apply a 236 mm x 236 mm probe to the front of a car in order to determine the bumper corners.

The radius of curvature of the wraparound windscreen may be physically tested using a radius gauge. This gauge may be used as a go/no-go gauge, by setting it to 150 mm and observing whether any aspect of the tested wraparound windscreen edge has a radius of curvature smaller than the gauge.

4 Ongoing observations

4.1 Glare and visual artefacts

In discussions around these geometric requirements, two issues have been raised as potential disbenefits associated with the improvements for VRU protection. These are:

1. That the vertical rake of the windscreen may refract light from overhead sources (such as street lights and the sun) creating glare for the driver.
2. That the horizontal curvature of the windscreen may create apparitions or visual artefacts that distort direct vision for the driver, particularly towards the corners of the screen.

As these minimum requirements do not take bus front end geometries beyond that of existing designs, it is considered that these potential issues are not perceived to be critical factors above that already accepted as common practice within the current fleet. However, operators should be mindful of the potential and will be expected to log and feedback any potential issues, if substantiated reports become available.

Attachment 39: Bus Front End Geometry Test and Assessment Protocol

1 Introduction

This document presents a procedure, hereon referred to as the Front End Geometry Test (FEGT), for objectively measuring the global geometry of a bus front end for the purposes of requiring a design that optimises the kinematics of collisions between bus front ends and vulnerable road users to mitigate the risks of injury and run-over events.

For full understanding of this Attachment it should be read in conjunction with the New Bus Specification, Section 4.6.2 and Attachment 40 - Bus Front End Design – Enhanced Geometric Requirements Guidance Notes

2 Scope

This protocol applies to all new buses intended for service under contract to TfL that are passenger vehicles with a maximum mass exceeding 5 tonnes and a capacity exceeding 22 passengers. The passenger vehicles will be capable of carrying seated but unrestrained occupants and standing occupants. Such vehicles are categorised by the Consolidated Resolution on the Construction of Vehicles (R.E.3) as M_3[1]; Class I.

3 Purpose

The purpose of this test and assessment protocol is to bring about an improvement in the global geometry of the front end of buses which have been identified as a principle cause of injuries when involved in collisions with vulnerable road users (pedestrians, cyclists and motorcyclists).

The vehicles tested under the Front End Geometry Test (FEGT) are representative of the majority of buses in circulation in the urban environment where there is a significant potential for bus collisions with pedestrians and other vulnerable road users.

[1] As defined by European Type Approval Framework Directive 2007/46/EC

4 Normative References

The following normative documents, in whole or in part, are referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

- London Bus Service Limited New Bus Specification Section 4.6.2
- London Bus Service Limited New Bus Specification – Attachment 40: Bus Front End Design – Enhanced Geometric Requirements Guidance Notes
- Directive 2007/46/EC of the European Parliament and of the Council establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles.
- Regulation (EU) 2018/858 of the European Parliament and of the Council of 30th May 2018 on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles, amending Regulations (EC) No 715/2007 and (EC) No 595/2009 and repealing Directive 2007/46/EC.

5 Definitions

For the purposes of this protocol:

- **A-pillar** - means the foremost and outermost roof support extending from the chassis to the roof of the vehicle.
- **Bus front end** - means all outer structures of the front end of the vehicle exposed to a potential collision with a VRU. It may therefore include, but is not limited to, the bumper, the bonnet or grille, scuttle, wiper spindles, lower windscreen frame, the windscreen, the windscreen header and the A-pillars.
- **Bus front end geometry envelope** - means the range of horizontal angles and vertical rake angles for each test position, outside of which the bus front end would be considered to be non-compliant.
- **Driver mass** - means the nominal mass of a driver that shall be [68] kg.
- **Front End Geometry Performance Evaluation Tool** - means the spreadsheet tool used to assess the safety performance of the global geometric characteristics of the bus front end
- **Frontal plane** - means a plane perpendicular to the median longitudinal plane of the vehicle and touching its foremost point, disregarding the projection of devices for indirect vision and any part of the vehicle greater than 2.0 m above the ground.
- **Ground reference plane** - means a horizontal plane that passes through the lowest points of contact for all tyres of a vehicle with its mass in running order. If the vehicle is resting on the ground, then the ground level and the ground reference plane are one and the same. If the vehicle is raised off the ground such as to allow extra clearance, then the ground reference plane is above ground level; and if the vehicle (perhaps a test sample) is lower than it would

be in running order, then the ground reference plane is below the ground level.

- **Global coordinate system** - means the coordinate system located with its origin at the intersect of the longitudinal median plane of the vehicle, the frontal plane and the ground reference plane and its axes orientated such that the positive X-axis is directed forward, the positive Y-axis is directed towards the offside of the vehicle and the positive Z-axis is directed upward.
- **Horizontal angle** - means the angle measured at each test point between the frontal plane of the bus and the tangent to the bus front end structures in a plane parallel to the horizontal plane of the vehicle.
- **Inboard** - means in a direction toward the median longitudinal plane.
- **Lower test reference line** - means the geometric trace on the bus front end of a horizontal plane located at a wrap around distance of 750±10 mm above the ground reference plane.
- **Mass in running order** - means the nominal mass of a vehicle as determined by the sum of the unladen mass and driver's mass.
- **Measuring point** - means the location on the bus front end at which the horizontal angle and vertical rake angle values are measured.
- **Median longitudinal plane** - means the centreline of the subject vehicle parallel to the forward direction of travel.
- **Nearside** - means the left-hand side (i.e. passenger side) of the subject vehicle.
- **Offside** - means the right-hand side (i.e. driver side) of the subject vehicle.
- **Outboard** - means in a direction away from the median longitudinal plane.
- **Side reference line** - means the geometric trace of the most outboard points of contact between a straight edge 700mm long and the sides of the vehicle, when the straight edge, held parallel to the transverse horizontal plane of the vehicle and inclined rearwards by 75°, is traversed rearwards to contact the sides of the bus front end (Figure 39_1).

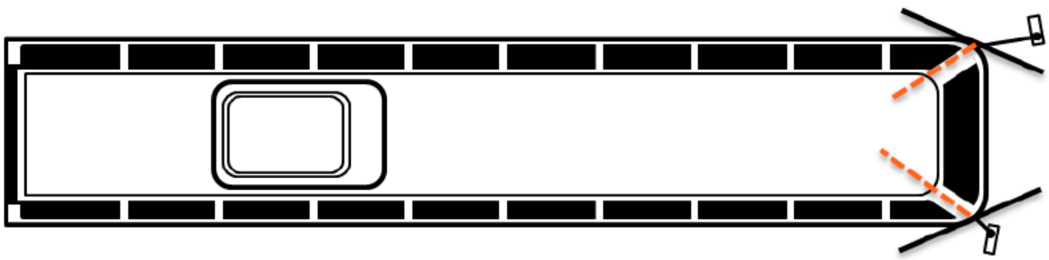

Figure 39_1a: Side reference line – plan view

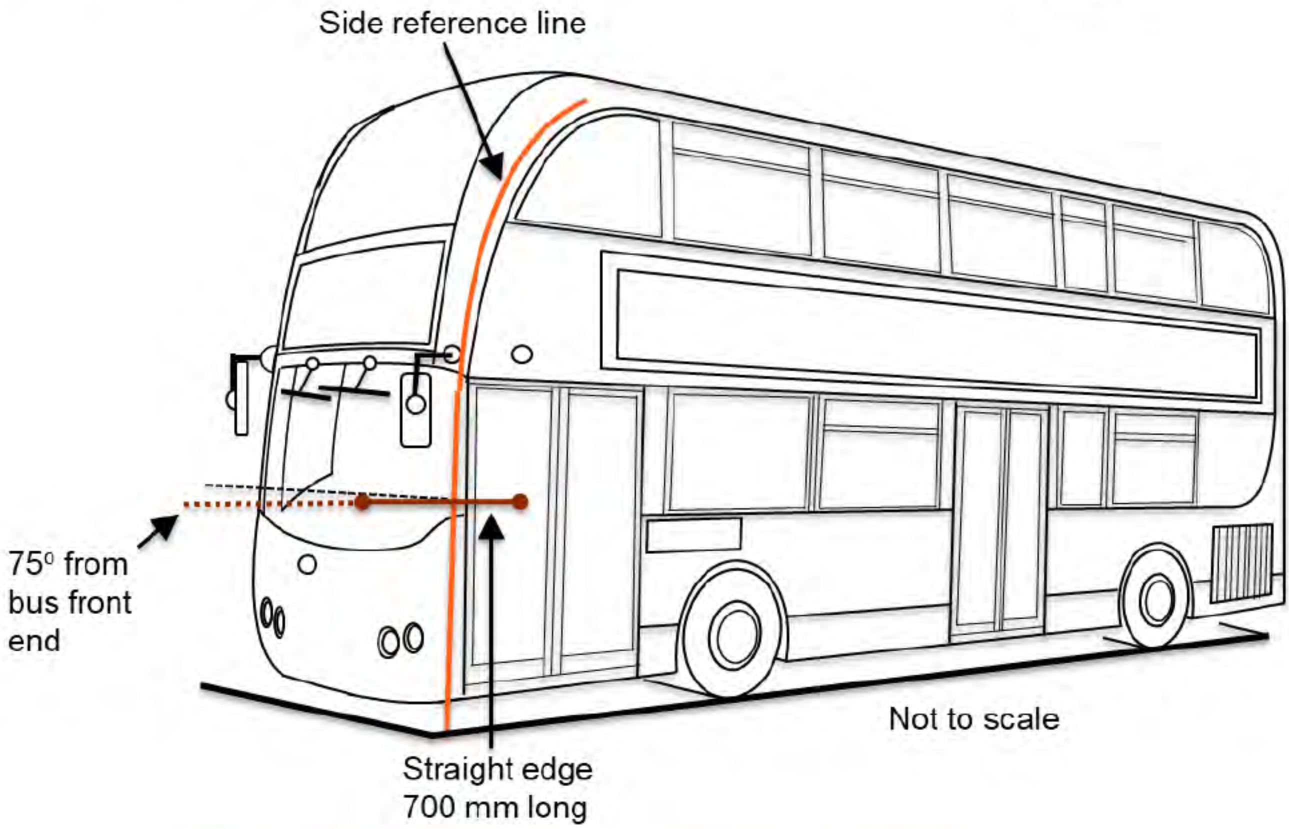

Figure 39_1b: Side reference line – front/side view

- **Subject vehicle** - means the vehicle being tested.
- **Test position** - means the position used to locate the measuring point in the Y-axis on the bus front end. Each test position shall extend between the lower and upper test reference lines. Five test positions are specified:
    - Outboard nearside test position (P1), with test points located at a horizontal wrap around distance of 150 mm inboard from the nearside side reference line.
    - Inboard nearside test position (P2), with test points located at a horizontal wrap around distance of 725 mm outboard from the median longitudinal plane and toward the nearside.
    - Central test position (P3), with test points located on the median longitudinal plane.
    - Inboard offside test position (P4), with test points located at a horizontal wrap around distance of 725 mm outboard from the median longitudinal plane and toward the offside.
    - Outboard offside test position (P5), with test points located at a horizontal wrap around distance of 150 mm inboard from the offside side reference line.
- **Test zone** - area on the bus front end structures bounded by the upper and lower test reference lines and the nearside and offside reference lines.

- **Unladen mass** - means the nominal mass of a complete vehicle as determined by the following criteria:
  - Mass of the vehicle with bodywork and all factory fitted equipment, electrical and auxiliary equipment for normal operation of the vehicle, including liquids, tools, fire extinguisher, standard spare parts, chocks and spare wheel, if fitted.
  - The fuel tank shall be filled to at least 90 per cent of rated capacity and the other liquid containing systems (except those used for water) to 100 per cent of the capacity specified by the OEMs.
- **Upper test reference line** - means the geometric trace on the bus front end of a horizontal plane located at a wrap around distance of 2000±10 mm above the ground reference plane.
- **Vertical rake angle** - means the angle measured at each test point between the frontal plane of the bus and the tangent to the bus front end structures in a plane parallel to the median longitudinal plane of the vehicle.
- **Vehicle type with regard to enhanced geometry requirements** - means a category of vehicles with front end designs which, within the test zone, do not differ in such essential respects as:
  - The global geometric dimensions,
  - The external component arrangement,

  in so far as they may be considered to have a negative effect on the results of the impact tests prescribed in this Regulation.
- **Vulnerable road user (VRU)** - means an adult or child pedestrian or an adult or child cyclist
- **Wrap around distance** - means the geometric trace described on the outer surface of the bus front end structures by a flexible tape, when it is held in the vertical or horizontal plane of the vehicle and traversed across the bus front end. The tape is held taut throughout the operation with one end held at the origin of the measurement (see Figure 39_2).

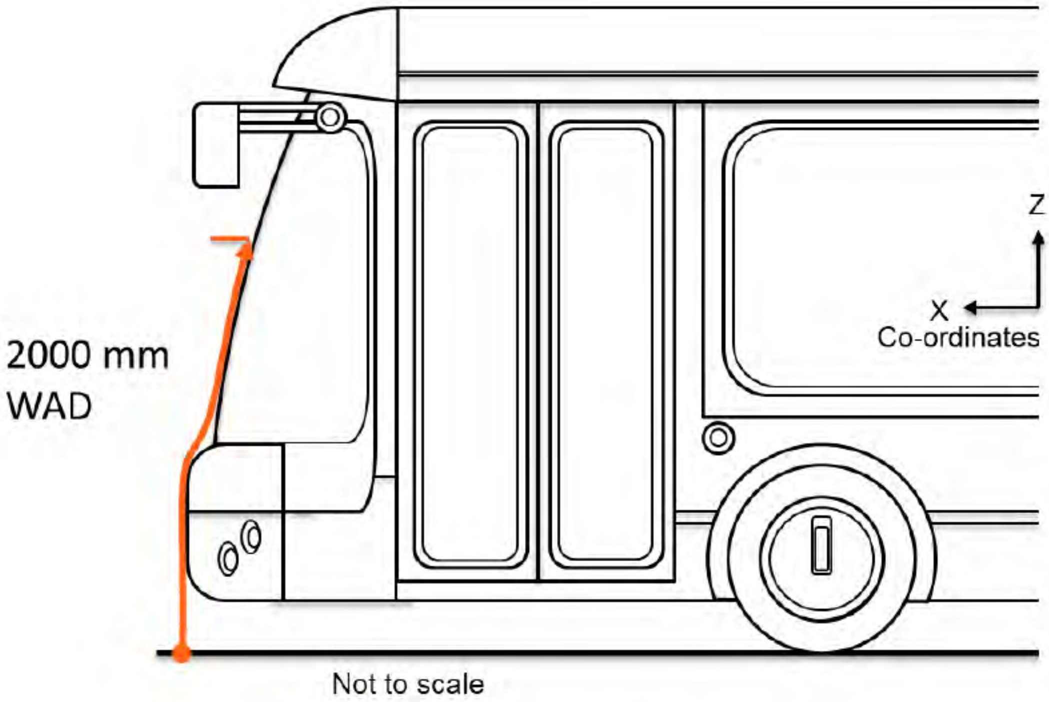

Figure 39_2: Wrap around distance measurement

6 Specifications

When tested in accordance with the test procedures in Section 7, the following minimum requirements shall be met:

a) All horizontal and vertical rake angles shall be compliant with the bus front end geometry envelope boundaries defined in Section 0.

b) A weighted bus front end geometry score (FEGS) of 0% (as defined in Section e)) shall be exceeded.

c) There shall be no more than eight safety performance criteria scores with a value of 0.

Bus front end geometry envelope boundaries

a) The bus front end geometry shall be compliant with the following boundary conditions:

b) Vertical rake angles for all measuring points at all test positions (P1-P5) shall be no less than 4° and no greater than 23°.

c) Horizontal angles for all measuring points at the outboard test positions (P1 and P5) shall be no less than 20° and no greater than 33°.

d) Horizontal angles for all measuring points at the inboard test positions (P2 and P4) shall be no less than 11° and no greater than 18°.

e) Weighted bus front end geometry score (FEGS)

The weighted FEGS shall be calculated for each subject vehicle using the following approach:

a) Safety performance scores shall be calculated for all safety performance measures (head injury risk, thoracic injury risk and run-over risk) at each impact position and each impact velocity using the Front End Geometry Performance Evaluation Tool provided.

b) The Front End Geometry Performance Evaluation Tool shall then be used to extract the FEGS for the bus front end of the subject vehicle.

c) The FEGS shall then be ranked according to the following star rating approach:

   1) 0 star: FEGS ≤ 0%
   2) 1 star: 0% < FEGS ≤ 10%
   3) star: 10% < FEGS ≤ 20%
   4) star: 20% < FEGS ≤ 30%
   5) star: 30% < FEGS ≤ 40%
   6) star: FEGS >40%

Vehicle types may be exempt from these requirements, should documentary evidence be provided to demonstrate to the Test Service how the geometric design of the subject vehicle bus front end reduces the risks of VRU injuries and run-overs relative to current bus designs.

A simulation based test and assessment approach shall be provided as evidence.

Although the OEMs has the responsibility to ensure such evidence provides sufficient assurance of real-world improvements in VRU injury and run-over risks, guidelines on a simulation based testing approach are provided in 0.

7 Test procedure

When performing measurements:

a) If the vehicle is fitted with a badge, mascot or other structure, which would bend back or retract under an applied load of maximum 100N, then this load shall be applied before and/or while these measurements are taken.

b) Any vehicle component which could change shape or position, other than suspension components or active devices to protect pedestrians, shall be set to their stowed position.

Vehicle set up:

a) The vehicle shall be tested with the mass in running order.

b) The side, upper and lower reference lines and the test positions shall be marked on the subject vehicle.

c) Three measuring points, with at least 500 mm wrap around distance between them, shall be marked on the vehicle for each test position.

Bus front end geometry measurements:

a) At each measuring point, the vertical rake angle and horizontal angle shall be assessed.

b) To ensure only the global geometric features of the bus front end are tested, these angles shall be assessed using a 236±5 mm x 236±5 mm rectangular plane, with its centre placed against the surface of the bus at the measuring point.

c) Assessment of weighted front end geometry scores (FEGS):

d) Input the vertical rake angle, to the nearest degree, for all measuring points at all test positions (P1-P5) to the Front End Geometry Performance Evaluation Tool.

e) Input the horizontal angle, to the nearest degree, for all measuring points at the inboard and outboard test positions (P1, P2, P4 and P5) to the Front End Geometry Performance Evaluation Tool.

Extract and report the following criteria:

a) The weighted FEGS.

b) The number of safety performance criteria scores with a value of 0.

c) The bus front end geometry envelope compliance status.

d) The star rating score.

Approaches other than the above procedure, such as CAD based methods, may be considered as equivalent by the Test Service, should documentary evidence be provided to verify that the requirements of the test procedures described in this Section have been met.

8 Test Report

The Test Service shall provide a comprehensive Test Report that will be made available to TfL. The test report shall consist of three distinct sections:

a) Reference information

b) Confirmation of protocol compliance

c) Performance data

8.1 Reference information

As a minimum, the Test Service shall provide reference information including:

a) Make (trade name of OEMs)

b) Model/Type

c) Commercial name(s) (if available)

d) Means of identification of type, if marked on the vehicle

e) Location of that marking

f) Variant (if applicable)

g) Category of vehicle

h) Name and address of OEMs

i) Name(s) and address(es) of assembly plant(s)

j) Name and address of the OEMs's representative (if any)

k) General construction characteristics of the vehicle

l) Photographs and/or drawings of a representative vehicle

m) Bodywork

n) Type of bodywork

o) Materials used and methods of construction

p) Running order information

q) A detailed description, including photographs and/or drawings, of the vehicle with respect to the structure, the dimensions, the relevant reference lines and the exterior bodywork of the frontal part of the vehicle shall be provided

8.2 Confirmation of protocol compliance

a) Predominantly this item will relate to providing a description of testing completed.

b) The measuring points tested by the laboratories shall be indicated in the test report. The test position and height from the ground plane of each measuring point shall be noted, as well as specific descriptions of the structures at the test point.

c) Photographs should identify the measuring points before testing.

8.3 Performance data

All vertical rake and horizontal angles for each measurement point shall be reported, alongside their positions relative to the global coordinate system (Table 39_ provides a blank example template of this table).

The safety performance criteria scores for each test position, vehicle speed and injury criteria shall be reported, taking the values reported by the Front End Geometry Performance Evaluation Tool (Figure 39_3).

The weighted FEGS, the number of safety performance criteria scores with as value of 0, the bus front end geometry envelope compliance status and the star rating shall be reported, taking these values reported by the Front End Geometry Performance Evaluation Tool (Figure 39_3).

Table 39_1: Example table for reporting of measurement point results

Test Position	Measurement Point Y Position	Measurement Point Z Position	Vertical Rake Angle	Horizontal Angle
P1-1	WWW mm	XXX mm	YY°	ZZ°
P1-2				
P1-3				
P2-1				
P2-2				
P2-3				
P3-1				
P3-2				
P3-3				
P4-1				
P4-2				
P4-3				
P5-1				
P5-2				
P5-3				

Safety Performance Criteria Scores		
HIC	Rib Deflection (mm)	Run-Over Proximity (m)
1	0	1
0	1	2
1	1	2
1	1	1
1	2	0
1	2	1
0	2	0
1	2	2
0	1	1
2	2	2
2	2	1
2	2	2
2	2	0
0	1	1
1	2	2

Weighted Front End Geometry Score	26.7%
Safety Performance Criteria Scores with a Value of 0	8
Front End Geometry Envelope Compliance	PASS
Bus Front End Geometry Star Rating	3

Figure 39_3: Example image showing results from front end geometry performance evaluation tool

Annex 1 - Simulation based testing guidelines

1 Introduction

The Vulnerable Road User (VRU) crashworthiness enhanced bus front end geometry requirements are intended to improve protection for VRUs during the primary impact of a collision and reduce the risks of VRUs being run over subsequently.

The clause on simulation evidence in the requirements permit an alternative pathway for compliance, whereby the intentions of these enhanced geometry requirements may be satisfied via a simulation based approach.

While ultimately the responsibility for ensuring sufficient real-world improvements in VRU injury and run-over risks remains with the OEMs, this Annex sets out a series of guidelines for simulation based approaches to be considered as equivalent evidence when compared to the requirements of the previously defined bus front end geometry test and assessment protocols.

2 Simulation Set Up Guidelines

2.1 Bus model validation

The geometry of the bus front end and structures is expected to come from CAD files of the bus and formed of suitably accurate representations of at least the bus front end components.

The material properties and the simulated structures should be tuned in a correlation exercise in order to develop a representative material model. This should be correlated against test data; for instance, comparing headform kinematics between physical and simulated tests against the flat, curved and/or wraparound areas of the windscreen. This model validation should occur before the simulations are performed to satisfy the requirements of the simulation approach.

It is recognised that there is a balance to be struck between quality of the simulation output and computational efficiency. However, it is expected that the simulation output is validated against physical (test) evidence and that this validation forms part of the simulation evidence package. It is anticipated that the testing is based on designs produced by the OEMs, rather than third party data, so that the correlation in bus front end response and VRU protection can be understood in terms of the detailed design approach adopted by the OEMs.

Pilot simulations should be used to assess whether the model produces a range of responses that are reasonable and reliable. Things to consider are:

- All VRU body parts are capable of contacting, where appropriate, with the bus front end components with a representative response during the simulations
- There are no simulation artefacts that significantly govern the response of the model (i.e. penetration through surfaces).

This approach may accept developmental models to support the validation as long as they are representative of the final design of the subject vehicle; it doesn’t have to be the final production (pre-production) design.

2.2 VRU surrogate models

As there is a need to avoid protection that is highly optimised for any single VRU size or type (e.g. a 50th percentile male pedestrian). Instead, the design approach to safety should intend to provide equivalent protection across all vulnerable road users.

In the evidence package it is recommended that the simulations generally concentrate on a single size/type of VRU model, such as the 50th percentile male pedestrian. This VRU model should be used to look for and demonstrate any improvements in safety over the baseline case.

Supplementing this there should then be an initiative to explore potential degradation in safety performance for other sizes or types of VRU.

The choice of other VRUs to be considered in the modelling should follow a sensible review of structural changes in the front end design of the bus. For instance, if there is a discontinuity in the surface profile around 1.5 m from the road, then testing with a large child or small adult would be important to explore and understand the implication of that profile for frontal crashworthiness and VRU protection. Cyclist models shall also be investigated.

The most representative approximation of a VRU should be sought in developing the simulation evidence. This may be taken to infer the use of detailed human body models (for example the Toyota Total Human Model for Safety (THUMS[2]), or the Global Human Body Modelling Consortium model (GHBMC[3])). However, it is appreciated that not all suppliers of simulation capabilities have access to these detailed human body models (and the associated compute time) at reasonable costs. Therefore alternatives may be sought.

In prior work TfL's technical partner has gained experience with frontal VRU crashworthiness simulations with a standing or cycling variant of a Hybrid III crash test dummy model. Simulation validity (biofidelity) was observed to improve with the addition of a more compliant shoulder and chest. Therefore, when using alternative VRU surrogates, such as crash test dummy models, it is recommended that the at least the thorax and shoulder of the surrogate have been developed for use in VRU or side impact specific simulations.

2.3 VRU manoeuvres

There is also a need to avoid protection that is highly optimised for any one type of VRU motion (walking, running or cycling behaviour). It is important to consider that in a potential collision with a VRU, their behaviour could be from a relatively wide variety of walking, running or cycling speeds and with any horizontal travel direction vector. It is important to have confidence that these variations do not lead to poor interactions with the bus front end which would give a concern for VRU frontal crashworthiness.

Several impact positions should be evaluated across the width of the bus front end. Whether or not the bus is symmetrical about the central vertical and longitudinal plane, it is likely to require testing the bus front on the right and left for a VRU

[2] https://global.toyota/en/newsroom/corporate/26497281.html
[3] https://www.elemance.com/

travelling from one side to the other. This is because the VRU will have its own velocity which may influence the interaction with the bus front end and the rebound speed and direction. As such, a minimum of five test positions is recommended, as specified in the previous requirements, to account for horizontal curvature changes across the bus front end.

The position of the legs (for instance, where they are in the ‘gait’ cycle) of the VRU has also been shown to influence the interaction of the VRU with the bus front end. This potential variation in interaction should also be built into the simulation matrix so that confidence is given to the range of outputs and their ability to account for this effect. This will help in understanding the sensitivity of the design to likely collision scenarios and should be used to capture the worst case for protection.

2.4 Simulation boundary conditions

There is a need to avoid protection that is highly optimised for a single set of boundary conditions (e.g. collision speeds). The boundary conditions for the simulations should cover the range of realistic inputs. This will mean evaluating simulation outcomes with deliberately selected:

- Closing speeds
  - With representative bus speeds
    - For example, a range of 10 to 30 mph is reasonable based on travel speeds and collision case data
    - A single evaluation point could be used (e.g. 20 mph) for the major part of a simulation matrix assuming that the variation with speed was shown to be predictable in a subset of the tests
  - With representative travel speed for the VRUs
    - A range of 2 to 8 m/s could be used to represent reasonable walking and running behaviours of a pedestrian
    - Again, a smaller set of speeds could be used in the simulation matrix if it could be demonstrated that worst case interactions were understood in the derivation of that matrix
- Contact friction
  - Some friction with the ground is necessary
  - 0.6 has been used as the coefficient of friction in prior research work
- Braking vehicle dynamics
  - A representative braking rate shall be selected for use in determining the risk of a run-over, with -3.5 m/s^2 previously used. To simplify the braking response, this may be assumed as a constant braking rate (i.e. no need to model driver reaction and brake build up times).
  - It is suggested that some diving (forward pitching) of the bus front can be expected in many collision scenarios due to the pre-impact braking response
  - A representative forward pitch for the subject vehicle should be chosen for simulaitons to reflect potential collision scenarios and possible worst case interactions for the VRU
- Start and finish times for simulation runs
  - The start time should be prior to the first contact between bus and VRU
  - The finish time should allow adequate prediction of VRU throw characteristics to assess the risk for the bus running over the VRU after the primary interaction

3 Assessment of safety performance

The objective of the VRU crashworthiness safety measure is to assess injury causing consequences and demonstrate that a design for a bus front improves protection for VRUs during the primary impact, whilst reducing the risks of VRUs being subsequently run over. The requirements of this alternative compliance path are that the simulations provide an assessment of both direct contact injury risk and the subsequent ‘run-over’ risk.

To demonstrate safety performance improvements any new subject vehicle shall be compared against a database of responses built around a bus front end design that is representative of current/past geometries and structures. This shall be used to assess head and chest injury risk and the subsequent risk of being run-over for the VRU, due to these injury mechanisms being associated with the greatest risks of fatal and severe VRU collision injuries.

Although many injury risk metrics for each body region exist, and may be accepted if appropriately justified, a recommended dataset of metrics for the simulation outcomes is provided below:

- Head injury risk
  - 15 ms Head Injury Criteria (HIC_{15})
- Chest injury risk
  - Rib deflection distance
- Run-over risk
  - Proportion of collisions with a minimum clearance of <0.5 m, at any point in time during the collision, between the trajectory of the bus front end structures and VRU centre of gravity

Further detail on the average injury risk metrics across all five test positions and three different impact speeds for current best-in-class bus designs, as determined through simulations performed on behalf of TfL, may be found below in Table 39_2. These values may be used as comparators to assess the relative VRU safety performance of the subject vehicle, but should always be placed in the context of the range of VRU surrogate models and boundary conditions investigated by the specific evidence pack provided by the OEMs.

Table 39_2: Average injury risk metrics for HIC_{15} and lateral rib deflection injury metrics and proportion of run-over events across all five test positions for collisions at three representative impact speeds

Vehicle Speed	HIC_{15}	Lateral Rib Deflection (mm)	Run Over Risk (m)
10mph	21.5	13.5	0%
20mph	254.6	25.6	20%
30mph	739.7	37.3	60%

Alternatively, the subject vehicle may be directly compared to an earlier vehicle design from the OEMs (ensuring that this earlier design was the latest variant that was type approved before 2019). For this analysis an overall improvement in outcome must be shown with the subject vehicle when directly compared to the earlier vehicle design, with outcomes and criteria for both buses following the approaches defined in these sections. Both buses would be expected to be appropriately modelled and validated.

4 Example Simulation Matrix

As specified in the previous sections, the responsibility lies with the OEMs for deriving a simulation matrix to assure the Test Service that the changes in bus front end design results in an overall improvement in VRU safety and that any unintended consequences for a particular collision scenario have been mitigated.

Such a simulation matrix should include consideration of the following elements:

- VRU type
- VRU size
- VRU impact position
- VRU speed
- VRU gait
- Bus speeds

An example of such a matrix is shown below in Table 39_3, however, it is expected that OEMs propose their own matrices to prove overall improvements in injury and no unintended consequences to the Test Service.

Table 39_3: Indicative simulation matrix

#	Size	Impact Position	VRU activity	Struck-side leg position	Bus speed
1	Adult male (50th percentile)	P1	Walking	Forward	20 mph
2	Adult male (50th percentile)	P2	Walking	Forward	20 mph
3	Adult male (50th percentile)	P3	Walking	Forward	20 mph
4	Adult male (50th percentile)	P4	Walking	Forward	20 mph
5	Adult male (50th percentile)	P5	Walking	Forward	20 mph
6	Adult male (50th percentile)	P1	Running	Forward	20 mph
7	Adult male (50th percentile)	P4	Running	Forward	20 mph
8	Adult male (50th percentile)	P1	Cycling	Forward	20 mph
9	Adult male (50th percentile)	P3	Cycling	Forward	20 mph
10	Adult male (50th percentile)	P4	Cycling	Forward	20 mph
11	Adult male (50th percentile)	P3	Walking	Together	20 mph
12	Adult male (50th percentile)	P3	Walking	Behind	20 mph
13	Adult male (50th percentile)	P1	Walking	Together	20 mph
14	Adult male (50th percentile)	P1	Walking	Behind	20 mph
15	Adult male (50th percentile)	P3	Walking	Forward	10 mph
16	Adult male (50th percentile)	P3	Walking	Forward	30 mph
17	Adult male (50th percentile)	P2	Walking	Forward	10 mph
18	Adult male (50th percentile)	P2	Walking	Forward	30 mph
19	Child (10 years')	P1	Walking	Forward	20 mph
20	Child (10 years')	P3	Walking	Forward	20 mph
21	Child (10 years')	P4	Walking	Forward	20 mph

Attachment 40: Bus Front End Design – Enhanced Geometric Requirements Guidance Notes

(Vulnerable Road User (VRU) Frontal Crashworthiness)

1 Introduction

Bus fronts have been identified as one of the key injury-causing contact areas of the vehicle in collisions between buses and Vulnerable Road Users (VRU). Therefore, all bus front ends are required to have a global geometric design that both improves protection for VRUs during the primary impact of a collision and reduce the risks of VRUs being run over subsequently.

As such, all new buses shall have a front end design that complies with the Vulnerable Road User (VRU) crashworthiness enhanced bus front end geometry requirements for both vertical rake and horizontal curvature.

This document sets out the guidance notes related to the assessment of the global bus front end geometry and specifically, with respect to the enhanced requirements contained in Section 4.6.2 and Attachment 39 of the Bus Vehicle Specification. These guidance notes are aimed at bus operators and OEMs as a practical guide for implementation of the requirements as specified by the Bus Vehicle Specification.

These notes are for guidance only, and are not legally binding. In all circumstances, the guidance provided by an OEM or system supplier shall take precedence, and these guidance notes are only for use in the absence of other information. These are not intended to be exhaustive, but to point the operators toward practical advice and questions to raise with OEMs/suppliers.

2 Selection of buses/systems

From 2024, all new buses shall have a front end geometry that complies with the enhanced bus front end geometry requirements for both vertical rake angle and horizontal curvature. Therefore, selection can be any bus that is compliant with these specifications.

2.1 Intention of the requirements

The enhanced bus front end geometry requirements intend to mandate bus front end designs that implement a progressively curved (in the horizontal plane) and raked (i.e. vertically angled) design.

It was observed, in research performed that impacts against curved and raked bus front ends improved VRU injury and run over risks relative to traditional flat-fronted designs. This benefit was, however, limited to a particular optimised design envelope, with this enhanced bus front end geometry envelope found to considerably improve risks relative to current bus front end designs (i.e. larger/smaller vertical rake angles and shallower/deeper horizontal curvatures therefore did not improve VRU injury and run over risks).

It was also found within this research that the geometric design of bus front ends could be further optimised within the enhanced bus front end geometry envelope. This would provide additional casualty saving benefits, beyond that of bus front end geometries at the boundaries of the design envelope. This relationship is, however, highly complex and non-linear due to the many interactions between the various variables involved in such collisions. To this end, these requirements also specify the use of a bus front end geometry performance evaluation tool to provide guidance to users on the relative safety performance level of their designs.

Due to the complex nature of the interactions between variables for these collisions, these requirements also provide OEMs with an alternate compliance pathway. This permits OEMs to evidence improvements in the safety performance of the bus front end through a simulation-based approach, rather than by demonstrating compliance with the enhanced bus front end geometry envelope. OEMs are required to prepare a dossier of evidence that ensures that their simulations are of an appropriate quality and that they demonstrate improvements in safety across a range of expected VRU collision scenarios.

These requirements therefore seek to mandate the design of bus front end geometries for new buses into the TfL network to improve VRU injury and run-over risks relative to current designs. These requirements also seek to promote the design of new bus front ends that optimise the interaction of the VRU with the bus to further reduce the overall risks of injury and run-over.

2.2 Interpreting the requirements and selecting the most effective way to fulfil them

To achieve compliance with these enhanced bus front end geometry requirements, changes in bus lengths or capacity, driven by the raking and curvature of the bus front end, may be expected. Extended bus front end lengths or an increase in the rearward sweep of the bus front end may either be adopted to meet these design requirements, with both approaches needing to consider the impact they would have on operations. The extension of the front end may be expected to impact the turning circle, approach angle, ramp angle and stabling capacity of the bus, whilst an increase in the rearward sweep could impact door positioning, available passenger capacity and accessibility.

Information should therefore be sought by operators to understand the impact that the design approach adopted by the OEMs would have on operational constraints. This said, the enhanced bus front end geometry envelope requirements permit a range of vertical rake and horizontal curvature for selection. The minimum impact this design envelope should have on bus front end lengths is an extension of circa 300 mm at the longitudinal centreline of the bus, with similar distances rearward at the edges of the bus should there be no length extension.

It is advised that no extension should exceed 300 mm at the centreline (relative to current models) if a bus is likely to operate in space-constrained environments (depots or bus routes). Furthermore, a greater horizontal curvature of the bus front end may be employed by bus manufacturers/designers to control the outer turning radius of the bus and aid the manoeuvrability of the vehicle.

The enhanced requirements are intended to dictate a progressive surface geometry for the bus front end to bring about improvements in vulnerable road user protection. It is expected that the surface is broadly continuous in this regard. However, it is also recognised that necessary features are incorporated in the bus front end for functional reasons and styling. Experience from the car industry suggests that small projections and protrusions can be used to provide localised areas of angled surfaces. The most effective vulnerable road user protection will be realised if the geometry requirements are adopted generally, the greater the size of the areas presenting that angle then the more effective the measure will be.

2.3 Compliance and warranty

The enhanced geometry requirements may be assessed against a new build bus. It is expected that existing designs will not be fully compliant. Therefore new build buses will be required before full compliance with these requirements can be demonstrated.

Bus operators should ask to see documentary evidence of compliance with these requirements. Compliance may be established through either a CAD-based approach or physical testing. Whichever approach is adopted, a dossier of inspection points and measurements should be provided to assure compliance.

2.4 Features sharing other functional requirements

It is important to ensure that the front end of a bus performs well in other crash and failure modes, such as with other buses, HGVs and cars. This would require stiffer structural members within the broad VRU contact area. It is advised that protection in these other modes is considered at the same time as implementing design changes aimed at protecting VRUs. This is needed to deliver protection to both the bus drivers, other road users and VRUs.

One option is to use UN Regulation 29 (with regard to the protection of cab occupants of a commercial vehicle), and this has already been used by some OEMs. The geometry of category M3 buses is quite different to other vehicles, so the geometric and structural interactions with other vehicles must be carefully considered, and other tests may also be relevant. TfL is not yet making any requirements on this topic, but is recommending any new bus designs consider the interactions with a wide range of collision partners. For iterative, evolving designs this is unlikely to present a problem, but for those bus fronts designed with a substantially different front end geometry, then additional care should be taken over preserving safety for the driver and for ensuring crash compatibility for collisions with other road users.

3 Training

3.1 For test houses

The nature of verifying compliance with the requirements will depend on whether it is demonstrated through CAD or physical testing.

For CAD assessments, appropriate sections should be cut to demonstrate bus front end geometry in a way that can be visualised against the requirements. Any inspection should be facilitated by applying tangents to the surface at the test point where the appropriate angles of vertical rake or horizontal curvature can be viewed.

For physical inspections, the vertical rake can be measured with an inclinometer, while the horizontal angle can be measured through a protractor arrangement that may be used to determine the horizontal angle relative to the frontal plane of the bus. Here it should be noted that the footprint for the measurements should be 236 ± 5 mm x 236 ± 5 mm. This is to ensure that only the global geometric features of the bus are considered by these requirements and that smaller features are considered to not have a significant effect on the outcomes of VRU collisions.

Test houses undertaking approval tests to UN Regulation No. 127 or UN Regulation GTR No. 9 will already possess the capability to apply a 236 mm x 236 mm probe to the front of a car in order to determine the bumper corners.

4 Ongoing observations

4.1 Glare and visual artefacts

In discussions around these geometric requirements, two issues have been raised as potential disbenefits associated with the improvements for VRUs protection. These are:

1. That the vertical rake of the windscreen may refract light from overhead sources (such as street lights and the sun) creating glare for the driver.
2. That the horizontal curvature of the windscreen may create apparitions or visual artefacts that distort direct vision for the driver, particularly towards the corners of the screen.

As these enhanced requirements will take the design envelopes for bus front end geometries beyond that of existing designs, it is feasible that these new designs may be susceptible to these issues. Therefore, operators should be mindful of the potential and will be expected to log and feedback any potential issues, if substantiated reports become available.

Attachment 41: Bus Front End Design – Wiper Protection Guidance Notes

(Vulnerable Road User (VRU) Frontal Crashworthiness)

1 Introduction

Bus fronts have been identified as one of the key contact causing parts of the vehicle in collisions with Vulnerable Road Users (VRU). Therefore, all bus front ends, in the region of potential head contacts, are required to have a construction that absorbs energy and protects VRUs in the event of a contact at that location on the vehicle.

As such, all buses shall have their VRU impact testing performance assessed against the associated VRU impact testing protocol. All buses shall have front ends which are energy absorbing or sufficiently compliant or frangible to meet the performance requirements.

This document sets out the guidance notes related to the assessment of VRU Impact Performance in the specific aspect of windscreen wipers. These guidance notes are aimed at bus operators and OEMs as a practical guide for implementation of the Bus Safety Standard.

These notes are for guidance only, and are not legally binding. In all circumstances, the guidance provided by an OEM or system supplier shall take precedence, and these guidance notes are only for use in the absence of other information. These are not intended to be exhaustive, but to point the operators toward practical advice and questions to raise with OEMs/suppliers.

For full understanding of this Attachment it should be read in conjunction with the New Bus Specification, Section 4.6.4 and Attachment 36: Bus Impact Test Standard Assessment Protocol

2 Selection of buses/systems

Any bus that meets the TfL Bus Vehicle Specification.

The windscreen wiper requirements may be assessed against a new build bus.

2.1 Compliance and warranty

A bus operator should ask to see one of two things from the OEM.

a) A statement confirming that the windscreen wipers are mounted at a height greater than 2.0 m from the ground plane – making them exempt from impact testing – applicable to all 'new entry buses'

b) If mounted at or below 2.0 m, documentation showing the vehicle is fitted with a protective covering and a VRU Impact Performance test report confirming that when impacted at the worst-case location, the head injury criterion (HIC_{15}) value was reduced by 50% when compared to the same location without a protective covering – applicable to all existing bus models.

2.2 Interpreting the requirements and selecting the most effective way to fulfil them

The most effective way of controlling head injury risk through potential contacts with the windscreen wipers is to move the mounting points out of the likely regions of the bus front end that may be contacted in a collision. Citing them above 2.0 m fulfils this requirement for most of the vulnerable road user population.

Another method of mitigating injury risk is to make the structures compliant, frangible or shielded by a protective element. The extent to which this has been achieved can be assessed practically through the impact test protocol. Assuming that the windscreen wiper is no more injurious than the surrounding region of the bus front end, then this secondary approach may be considered as an appropriate alternative to repositioning the wiper mounting points.

2.3 Direct vision

If the windscreen wiper mounting points have been altered between bus design iterations, then care must be taken to ensure that the swept area of the windscreen is at least maintained. This must still be compliant with direct vision requirements.

2.4 Indirect vision

The nearside mirror of a bus may be visible to the driver though the swept area of the windscreen. If this is the design philosophy adopted by an OEM, then this requirement should be preserved.

3 Training

3.1 For test houses

Test houses accredited to undertake approval tests to UN Regulation No. 127 or UN Regulation GTR No. 9 will be considered suitable to undertake performance tests. Test houses without such accreditation will be required to demonstrate to TfL at their expense that they can achieve the same standard of testing as an accredited organisation.

3.2 Bus maintenance engineers

The engineers carrying out general bus maintenance should be aware that access to the windscreen wipers may be more difficult with them mounted at more than 2.0 m from the ground. This is considered to be a minor effect.

Attachment 42: Complex Electronic Control Systems

1 General

This attachment defines the special requirements for documentation, fault strategy and verification with respect to the safety aspects of Complex electronic vehicle control systems (Definitions 4. below) as far as this attachment is concerned.

This attachment may also be called, by special paragraphs in this Regulation, for safety related functions which are controlled by electronic system(s).

This attachment does not specify the performance criteria for "The System" but covers the methodology applied to the design process and the information which must be disclosed to the Technical Service, for type approval purposes.

This information shall show that "The System" respects, under normal and fault conditions, all the appropriate performance requirements specified elsewhere in this Regulation.

For full understanding of this Attachment it should be read in conjunction with the New Bus Specification, Section 4.3.2, Attachment 15: Advanced Emergency Braking (AEB) Assessment Protocol and Attachment 16: Advanced Emergency Braking (AEB) Guidance Notes

2 Scope

This protocol applies to all new buses intended for service under contract to TfL that are passenger vehicles with a maximum mass exceeding 5 tonnes and a capacity exceeding 22 passengers. The passenger vehicles will be capable of carrying seated but unrestrained occupants and standing occupants. Such vehicles are categorised the Consolidated Resolution on the Construction of Vehicles (R.E.3) as M_3; Class I.

3 Normative References

- London Bus Services Limited New Bus Specification Section 4.3.2
- London Bus Services Limited Attachment 15: Advanced Emergency Braking (AEB) Assessment Protocol
- London Bus Services Limited Attachment 16: Advanced Emergency Braking (AEB) Guidance Notes

4 Definitions

For the purposes of this attachment:

- **Boundary of functional operation** defines the boundaries of the external physical limits within which the system is able to maintain control.
- **Complex electronic vehicle control systems** are those electronic control systems which are subject to a hierarchy of control in which a controlled function may be over-ridden by a higher level electronic control system/function.
  A function which is over-ridden becomes part of the complex system
- **Electronic control system** means a combination of units, designed to co-operate in the production of the stated vehicle control function by electronic data processing.
  Such systems, often controlled by software, are built from discrete functional components such as sensors, electronic control units and actuators and connected by transmission links. They may include mechanical, electro-pneumatic or electro-hydraulic elements.
  The System, referred to herein, is the one for which type approval is being sought.
- **Higher-level control** systems/functions are those which employ additional processing and/or sensing provisions to modify vehicle behaviour by commanding variations in the normal function(s) of the vehicle control system.
  This allows complex systems to automatically change their objectives with a priority which depends on the sensed circumstances.
- **Range of control** refers to an output variable and defines the range over which the system is likely to exercise control.
- **Safety concept** is a description of the measures designed into the system, for example within the electronic units, so as to address system integrity and thereby ensure safe operation even in the event of an electrical failure.
  The possibility of a fall-back to partial operation or even to a back-up system for vital vehicle functions may be a part of the safety concept.
- **Transmission links** are the means used for inter-connecting distributed units for the purpose of conveying signals, operating data or an energy supply.
  This equipment is generally electrical but may, in some part, be mechanical, pneumatic, hydraulic or optical.
- **Units** are the smallest divisions of system components which will be considered in this annex, since these combinations of components will be treated as single entities for purposes of identification, analysis or replacement.

5 Documentation

5.1 Requirements

The manufacturer shall provide a documentation package which gives access to the basic design of "The System" and the means by which it is linked to other vehicle systems or by which it directly controls output variables.

The function(s) of "The System" and the safety concept, as laid down by the manufacturer, shall be explained.

Documentation shall be brief, yet provide evidence that the design and development has had the benefit of expertise from all the system fields which are involved.

For periodic technical inspections, the documentation shall describe how the current operational status of "The System" can be checked.

Documentation shall be made available in 2 parts:

a. The formal documentation package for the approval, containing the material listed in Section 5. of this attachment (with the exception of that of Paragraph 8 of Section 5.4 below) which shall be supplied to the Technical Service at the time of submission of the type approval application. This will be taken as the basic reference for the verification process set out in section 4. of this attachment.
b. Additional material and analysis data of Paragraph 8 of Section 5.4 below, which shall be retained by the manufacturer, but made open for inspection at the time of type approval.

5.2 Description of the functions of "The System"

A description shall be provided which gives a simple explanation of all the control functions of "The System" and the methods employed to achieve the objectives, including a statement of the mechanism(s) by which control is exercised.

A list of all input and sensed variables shall be provided and the working range of these defined.

A list of all output variables which are controlled by "The System" shall be provided and an indication given, in each case, of whether the control is direct or via another vehicle system. The range of control exercised on each such variable shall be defined.

Limits defining the boundaries of functional operation (see section 4 Definitions of this attachment) shall be stated where appropriate to system performance.

5.3 System layout and schematics

5.3.1 Inventory of components

A list shall be provided, collating all the units of "The System" and mentioning the other vehicle systems which are needed to achieve the control function in question.

An outline schematic showing these units in combination shall be provided with both the equipment distribution and the interconnections made clear.

5.3.2 Functions of the units

The function of each unit of "The System" shall be outlined and the signals linking it with other Units or with other vehicle systems shall be shown. This may be provided by a labelled block diagram or other schematic, or by a description aided by such a diagram.

5.3.3 Interconnections

Interconnections within "The System" shall be shown by a circuit diagram for the electric transmission links, by an optical-fiber diagram for optical links, by a piping diagram for pneumatic or hydraulic transmission equipment and by a simplified diagrammatic layout for mechanical linkages.

5.3.4 Signal flow and priorities

There shall be a clear correspondence between these transmission links and the signals carried between units.

Priorities of signals on multiplexed data paths shall be stated, wherever priority may be an issue affecting performance or safety as far as this Regulation is concerned.

5.3.5 Identification of units

Each unit shall be clearly and unambiguously identifiable (e.g. by marking for hardware and marking or software output for software content) to provide corresponding hardware and documentation association.

Where functions are combined within a single Unit or indeed within a single computer, but shown in multiple blocks in the block diagram for clarity and ease of explanation, only a single hardware identification marking shall be used.

The manufacturer shall, by the use of this identification, affirm that the equipment supplied conforms to the corresponding document.

The identification defines the hardware and software version and, where the latter changes such as to alter the function of the unit as far as this Regulation is concerned, this identification shall also be changed.

5.4 Safety concept of the manufacturer

The manufacturer shall provide a statement which affirms that the strategy chosen to achieve "The System" objectives will not, under non-fault conditions, prejudice the safe operation of systems which are subject to the prescriptions of this Regulation.

In respect of software employed in "The System", the outline architecture shall be explained and the design methods and tools used shall be identified. The manufacturer shall be prepared, if required, to show some evidence of the means by which they determined the realisation of the system logic, during the design and development process.

The manufacturer shall provide the technical authorities with an explanation of the design provisions built into "The System" so as to generate safe operation under fault conditions. Possible design provisions for failure in "The System" are for example:

(a) Fall-back to operation using a partial system.

(b) Change-over to a separate back-up system.

(c) Removal of the high level function.

In case of a failure, the driver shall be warned for example by warning signal or message display. When the system is not deactivated by the driver, e.g. by turning the Ignition (run) switch to "off", or by switching off that particular function if a special switch is provided for that purpose, the warning shall be present as long as the fault condition persists.

If the chosen provision selects a partial performance mode of operation under certain fault conditions, then these conditions shall be stated and the resulting limits of effectiveness defined.

If the chosen provision selects a second (back-up) means to realize the vehicle control system objective, the principles of the change-over mechanism, the logic and level of redundancy and any built in back-up checking features shall be explained and the resulting limits of back-up effectiveness defined.

If the chosen provision selects the removal of the higher level function, all the corresponding output control signals associated with this function shall be inhibited, and in such a manner as to limit the transition disturbance.

Paragraph 8

The documentation shall be supported, by an analysis which shows, in overall terms, how the system will behave on the occurrence of any one of those specified faults which will have a bearing on vehicle control performance or safety.

This may be based on a Failure Mode and Effect Analysis (FMEA), a Fault Tree Analysis (FTA) or any similar process appropriate to system safety considerations.

The chosen analytical approach(es) shall be established and maintained by the manufacturer and shall be made open for inspection by the technical service at the time of the type approval.

This documentation shall itemize the parameters being monitored and shall set out, for each fault condition of the type defined in paragraph 8 above, the warning signal to be given to the driver and/or to service/technical inspection personnel.

6 Verification and test

The functional operation of "The System", as laid out in the documents required in Section 5. above, shall be tested as follows:

6.1 Verification of the function of "The System"

As the means of establishing the normal operational levels, verification of the performance of the vehicle system under non-fault conditions shall be conducted against the manufacturer's basic benchmark specification unless this is subject to a specified performance test as part of the approval procedure of this or another Regulation.

6.2 Verification of the safety concept

The reaction of "The System" shall, at the discretion of the Type Approval Authority, be checked under the influence of a failure in any individual unit by applying corresponding output signals to electrical units or mechanical elements in order to simulate the effects of internal faults within the unit.

The verification results shall correspond with the documented summary of the failure analysis, to a level of overall effect such that the safety concept and execution are confirmed as being adequate.

Attachment 43 - Bus Acceleration Performance Assessment Protocol

1 Introduction

Bus acceleration performance is limited to a maximum rate of 1.2 m/s^2 under all load conditions to afford adequate driving acceleration in the fully laden condition and for the benefit of passenger safety and comfort.

This document presents a test and data analysis method for objectively evaluating compliance with the acceleration performance limit.

2 Scope

This protocol applies to all new buses intended for service under contract to TfL that are passenger vehicles with a maximum mass exceeding 5 tonnes and a capacity exceeding 22 passengers. The passenger vehicles will be capable of carrying seated but unrestrained occupants and standing occupants. Such vehicles are categorised in the Consolidated Resolution on the Construction of Vehicles (R.E.3) as M3; Class I.

3 Purpose

The aim of this assessment is to achieve consistent evaluation of bus acceleration performance by specifying the test and data analysis methods for objectively assessing compliance with the acceleration performance limit.

This test and assessment protocol may be applied in collaboration with and OEM as a validation of data they provide, or independently as part of a market surveillance activity or any other reason as defined by the Approval Authority.

4 Normative references

The following normative documents, in whole or in part, are referenced in this document and are indispensable for its correct application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including and amendments) applies.

For full understanding of this attachment it should be read in conjunction with:

- London Bus Services Limited New Bus Specification: Section 4.3.1
- ISO 15037-2 Road vehicles – Vehicle dynamics test methods – Part 2: General conditions for heavy vehicles and buses

5 Definitions

For the purpose of this protocol:

- **Approval Authority** – The body within TfL that certifies that a bus is approved for use in the TfL fleet and assigns its result under the bus safety standard for us in procurement processes.
- **Forward acceleration** – Acceleration in the direction of the x-axis of the bus local coordinate system.
- **OEM: Original Equipment Manufacturer** – The business responsible for the manufacture of the bus being assessed.
- **Test Service** – The organisation undertaking the testing and certifying the result to the Approval Authority.
- **Vehicle Under Test** – The bus being assessed according to this protocol.

6 Reference system

A local coordinate system (x,y,z) for the VUT shall be defined such that the x-axis points towards the front of the bus, the y-axis towards the left and the z-axis upwards, as shown in Figure 43_1, below.

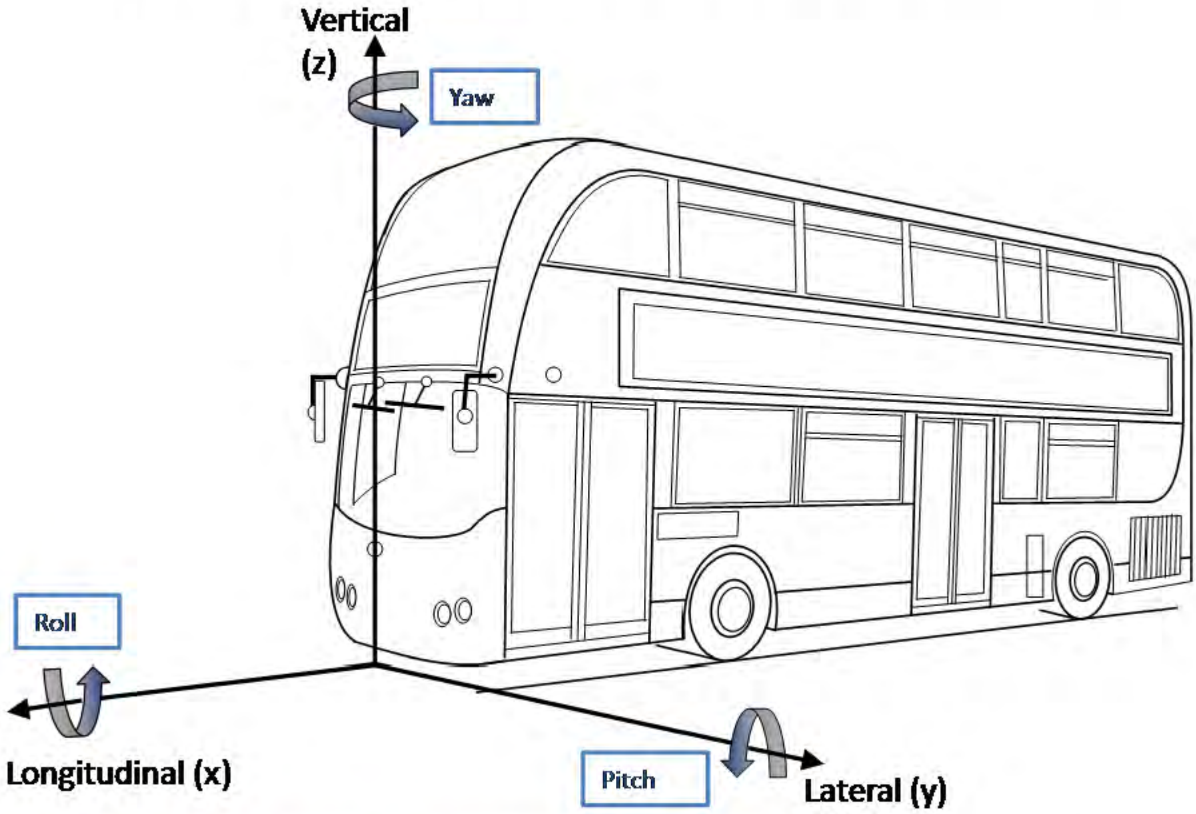

Figure 43_1: Local coordinate system and notation for VUT

The origin of the coordinate system shall lie on the ground plane, on the lateral centre line of the bus at its foremast point (ignoring the rear view mirror and the windscreen wipers).

7 Measurements and variables

7.1 Variables to be measured

Table 43_1 shows the variables which must be measured, along with the minimum operating ranges and measurement accuracy required.

Variable	Operating range (at least)	Measurement accuracy
Time	24 hours	GPS time
VUT speed (V_{VUT})	0 km/h to 80 km/h	0.1 km/h
VUT acceleration in x-axis (A_{VUTx})	± 15 m/s^2	0.01 m/s^2
Ambient temperature	-5 °C to +50 °C	± 1 °C
Track temperature	-5 °C to +50 °C	± 1 °C
Wind speed	0 m/s to 20 m/s	± 0.2 m/s

Table 43_1: Variables to be measure continuously during each test with minimum operating ranges and measurement accuracy

7.2 Measuring Equipment

Details of the sensors used to measure the required variables shall be recorded in the test report together with the position in which they are installed within the VUT (measured relative to the local coordinate system for the test vehicle).

The default equipment to be used shall be a high-quality inertial navigation system in combination with differential GPS. Alternatively any measuring equipment that can be demonstrated to be compliant with the requirements of ISO 15307-2 is permitted.

7.3 Data Recording and Post-processing

Data shall be recorded at a sampling rate of 100 Hz.

Speed requires no additional digital filtering after data capture.

Post-process x-axis acceleration with a symmetrically applied 0.1s moving window average smoothing filter.

8 Test Conditions

8.1 Test Track

Conduct tests on a nominally dry (no standing water), uniform, solid paved surface affording good friction with a maximum gradient of 2.5% in any direction and free of irregularities which may affect acceleration measurements.

8.2 Weather

Tests shall be conducted in dry conditions (no precipitation falling) with ambient temperature above 5 °C and below 40 °C. Wind speeds shall be below 5 m/s to minimise the effect on the VUT acceleration.

9 Vehicle Preparation

9.1 Tyres

Perform the testing with new (> 90% original tread depth across the tread width) original equipment tyres of the make, model, size, speed and load rating as specified by the OEM. Tyres shall be inflated to the manufacturers recommended pressure.

9.2 Running Order

All operating components likely to influence the outcome of the test shall be as specified by the manufacturer. Confirm that all VUT safety and operational systems are functioning correctly with no warning messages or indicators displayed to the driver. Rectify any faults before commencing testing.

When driven on the test track with the steering control centrally aligned, ensure the VUT exhibits good straight line driving order. In case of unsatisfactory driving order, undertake remedial work to return the geometry to within the OEM tolerances and confirm good driving order.

9.3 Vehicle Mass

The maximum rate of acceleration shall be less than 1.2 m/s^2 under all load conditions.

The VUT shall be tested and assessed in a nominally unladen condition with only the test driver and the test equipment on board.

Each axle of the vehicle shall be weighed in the condition as tested and the measurements recorded in the test report.

At the discretion of the Approval Authority, additional tests may be undertaken in full or partial load conditions to assess the extent of any performance variation compared to unladen.

9.4 Powertrain

For vehicles that incorporate a battery electric element in the propulsion powertrain, maintain the battery state of charge > 80% for the duration of the testing.

10 Test Procedure

10.1 Test Method

Before commencing acceleration testing, all relevant vehicle components shall be warmed up in order to achieve temperatures representative of normal driving conditions.

Select the transmission mode appropriate for normal driving. The acceleration performance of the VUT is assessed in two straight line driving manoeuvres:

1. Hold the VUT stationary using the service brake pedal, then release the service brake and fully apply the accelerator pedal immediately to accelerate the VUT at the maximum rate to at least 75% of the maximum design speed.
2. Drive the VUT at a steady speed of 8 ± 1 km/h for 3 seconds using the accelerator pedal and then fully apply the accelerator pedal immediately to accelerate the bus at the maximum rate to at least three quarters of the maximum design speed.

10.2 Number of Test Runs

Only one valid test is required for each manoeuvre and the result from the first valid test shall be the result officially recorded. If a test is found to be invalid or non-compliant, additional tests may be undertaken in order to investigate unexpected results at the discretion of the OEM, Test Service or Approval Authority. If so, the Test Service shall provide all data from repeat runs to the Approval Authority for their consideration.

11 Assessment of Results

Illustrate the test results by plotting a chart with time on the x-axis, VUT speed on the primary y-axis VUT x-axis acceleration on the secondary y-axis, scaling axes as appropriate, where acceleration is derived as per Section 7.3 above.

Also illustrate the 1.2 m/s^2 acceleration performance limit on the chart.

For the VUT to be deemed compliant with the acceleration performance limit requirement, the maximum rate of acceleration must be less than 1.2 m/s^2 under all load conditions.

Momentary exceedance of the acceleration limit as a result of noise on the measured signal will not render the vehicle non-compliant providing that the measured acceleration returns below the 1.2 m/s^2 within a maximum of 0.2 seconds.

12 Test Report

The Test service shall provide a comprehensive test report that will be made available to the Approval Authority. The test report shall consist of the following distinct sections and contents:

a) Details of the measurement equipment used
b) Records of all environmental validity data
c) Test results in the form of a chart presented as detailed in Section 11 above
d) All raw recorded acceleration data files in .csv or .xlsx format
e) Reference information.

The reference information required shall include as a minimum:

a) Vehicle make;
b) Vehicle model;
c) Vehicle model variant;
d) Evidence of meeting vehicle preparation requirements (e.g. MOT certificate, service history);
e) Details of the Test Service; and
f) Test date(s).

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