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March 6, 2019

VIA ELECTRONIC SUBMISSION: www.regulations.gov

Docket Management Facility
U.S. Department of Transportation
1200 New Jersey Avenue SE
West Building Ground Floor, Room W12-140
Washington, D.C. 20590-0001

RE: Docket No. NHTSA-2019-0102

The Truck and Engine Manufacturers Association ("EMA") hereby submits comments in response to the Request for Comments ("RFC") titled *Advanced Driver Assistance Systems Draft Research Test Procedures,* that the National Highway Traffic Safety Administration ("NHTSA" or the "Agency") recently published in the Federal Register. See, 84 Fed. Reg. 64,405 (November 21, 2019).

EMA represents the world's leading manufacturers of heavy-duty engines and commercial motor vehicles with the gross vehicle weight rating ("GVWR") greater than 10,000 pounds. EMA member companies manufacture highly customized medium- and heavy-duty vehicles to perform a wide variety of commercial functions including interstate trucking, regional freight shipping, local parcel pickup and delivery, refuse hauling, and construction. EMA member companies are developing and deploying Advanced Driver Assistance Systems ("ADAS") on the heavy trucks they produce. Accordingly, EMA and its member companies have a direct and significant interest in the draft research test procedure titled *Test Track Procedures for Heavy-Vehicle Forward Collision Warning and Automatic Emergency Braking Systems* ("AEB Test Procedure"). See, DOT HS 812 675, docket no. NHTSA-2019-0102-0009. Since it is the only test procedure in the RFC that directly applies to heavy vehicles, our comments focus on the draft AEB Test Procedure.

We applaud the Agency for developing the AEB Test Procedure and its solicitation of input on improving the procedure. We provide these comments in the constructive nature of NHTSA's RFC and we very much hope that they are helpful to the Agency. Additionally, we look forward to the opportunity to conduct vehicle tests to the draft procedure and using the results of those tests to further inform the finalization of the AEB Test Procedure.

We wholeheartedly endorse the Agency's goals that the AEB Test Procedure is to "objectively and practically assess the performance of ADAS technologies" and that the tests are "objective (*i.e.,* clear about exactly how they should be executed), and can be accurately and repeatedly performed. See, 84 Fed. Reg. at 64,405 and 64,406. In assessing the efficacy of the proposed AEB Test Procedure one key premise is that that heavy vehicle sector is extremely diverse, both in terms of the many sizes and configurations of vehicles that the sector encompasses, and the many different functions that those myriad vehicles serve. With sales volumes less than five percent that of passenger cars, and including significantly more diverse vehicles both in terms of sizes and configurations, heavy trucks are by no means not just big cars. Heavy trucks are work vehicles customized to suit each fleet's unique needs, and therefore each vehicle configuration is sold in very low volumes. Accordingly, test procedures that may be appropriate for the high-volume and narrow-scope passenger car market are not likely to work for the diverse and low-volume heavy truck sector. Heavy truck test procedures are most effective when they are carefully designed to be as time and cost efficient as possible, because the testing may apply only to a narrow set of vehicle configurations. At the same time, heavy truck testing must maintain the objectively, accuracy, and repeatability that are hallmarks of any effective vehicle test procedure.

Keeping in mind the unique needs of heavy truck industry, following are our comments on specific sections of the draft AEB Test Procedure:

Scope

The draft AEB Test Procedure includes in its scope collecting performance data on truck and buses with a gross vehicle weight rating (GVWR) over 10,000 pounds. That broad vehicle segment includes a wide variety of truck tractors, buses and single-unit trucks. The single-unit trucks captured by the test procedure's scope include: heavy-duty pickup trucks; step vans; box, tanker, stakebed and flatbed trucks; refuse trucks; dump trucks; concrete mixers, and many more types of trucks in GVWR Classes 3, 4, 5, 6, 7 and 8. Additionally, most of those vocational single-unit trucks are built in multiple stages, with the "truck" manufacturer building an incomplete chassis-cab that is completed by bodybuilder, potentially with additional manufacturing performed by another party (*e.g.,* installation of a pump, crane, liftgate, plow, or other equipment). Further, each of the manufacturers in the chain of building a single-unit vocational vehicle -- incomplete vehicle manufacturers, intermediate manufacturers and final-stage vehicles manufacturers -- have specific legal responsibility for certification to NHTSA's safety standards. See, 49 C.F.R. Part 568.

Forward Collision Warning (FCW) and AEB technologies are proving to be effective safety technologies on tractor-semitrailer combination vehicles. Accordingly, EMA member companies are installing an increasing number of the systems on the truck tractors they build. Since tractors travel at high speeds over long distances, and thus are exposed to more potential forward collision scenarios, FCW and AEB systems provide a significant safety benefit. However, the extension of those technologies to single-unit trucks remains in its infancy. The lower safety benefit of low-speed and low-mileage operation, the wide variety of vehicle configurations, each sold in very low volumes, plus the complications of multi-stage vehicle manufacturing, have all factored into what currently is very low adoption of CWD and AEB on single-unit trucks. Since a test procedure must be validated to prove that it is accurate and repeatable, and an insufficient number (potentially zero) single-unit trucks with AEB have been tested, NHTSA should modify the scope of the AEB Test Procedure to exclude single-unit trucks and buses built on truck chassis. Until the AEB Test Procedure is validated to be appropriate, accurate, and repeatable for other heavy vehicles, the Agency should limit it to truck tractors and motorcoaches.

General Test Conditions

Testing Surface

Section 1.3 of the AEB Test Procedure specifies a testing surface that is straight and flat. To ensure repeatable test results that can be used to accurately compare the performance of different vehicles and different AEB systems, there should be a tolerance on the flatness of the testing surface. Further, the tolerance should be aligned with SAE International Surface Vehicle Recommended Practice J3029, *Forward Collision Warning and Mitigation Vehicle Test Procedure – Truck and Bus*, OCT2015 ("SAE J3029"). Accordingly, the testing surface specification in the AEB Test Procedure should include a flatness tolerance of ±1%.

Brake Burnish

Section 1.3 the AEB Test Procedure requires burnishing the brakes prior to testing in accordance with FMVSS No. 105, 121 or 136. However, those standards do not include identical requirements for brake burnishing. To provide repeatable and comparable test results, the AEB Test Procedure should reference only the brake conditioning procedures in FMVSS No. 136, *Electronic Stability Control Systems for Heavy Vehicles*. See, 49 C.F.R. 571.136, S7.4. FMVSS No. 136 is the newest of the three standards, and it includes the highest allowable initial brake temperature (*i.e.,* up to 400 ºF) and thus provides the greatest consistency in brake conditioning and vehicle braking performance.

System Reset

AEB systems include an activation counter that will identify as a fault multiple identical event scenarios that cause system activation. The fault will illuminate the malfunction indicator lamp, and in certain cases may disable the system. Such system programming is a feature for real-world operation where repeated identical activations should not happen. That is why in section 1.3 the AEB Test Procedure calls for powering down the vehicle after each test. Powering the vehicle down will indeed reset the AEB system and restart the counter. However, the draft AEB test procedure calls for powering the vehicle down *for a minimum of three minutes*, and to do so *after each test run*. Those requirements are more than is needed and would consume a tremendous amount of time over the course of conducting many test runs, and therefore they are unnecessarily burdensome. To achieve the same result without wasting so much time, the AEB Test Procedure should require powering down the vehicle only after the activation counter identifies a fault and illuminates the AEB malfunction indicator lamp, and then require only momentarily powering down the vehicle. Once an AEB system loses power, it will reset the counter; there is no need to power down until after a fault occurs and there is no need to keep the vehicle off for three minutes.

Manual Transmission

During the Crash Imminent Braking ("CIB") tests in section 2.0 the AEB system may slow the vehicle to a stop. For a Subject Vehicle ("SV") with a manual transmission the driver must disengage the transmission clutch or the engine will stall. Section 1.3 of the AEB Test Procedure acknowledges this situation and in footnote 5 allows the test driver to disengage the clutch. However, the footnote calls for disengaging the clutch when the SV stops, which may be too late to keep the engine from stalling. To allow the test driver to disengage the clutch prior to engine stall, NHTSA should modify the footnote as shown below:

> [5] For an SV equipped with a manual transmission consideration should be given to disengagement of the clutch ~~when the SV stops~~ any time one second after the AEB system applies the brakes and prior to the SV stopping or the engine stalling. If the transmission clutch is engaged and a vehicle that is equipped with a manual transmission is topped the engine will also be stopped.

Speed Tolerance

In section 1.3 the draft AEB Test Procedure provides a tolerance of ±1.24 mph for initial vehicle speeds during the CIB tests. We believe that slightly expanding that tolerance would reduce the number of failed test runs without sacrificing test accuracy or repeatability. Maintaining the speed of a tractor-semitrailer combination vehicle can be challenging for a test driver and it consumes a significant amount of time to abort a test run and start another. To improve test efficiency, NHTSA should modify the AEB Test Procedure to provide a tolerance of ±2.0 mph for the initial test speeds. The variability of the rolling resistance of a loaded tractor-semitrailer combination vehicle would have a much greater impact on its deceleration after the driver releases the accelerator pedal than a ±2.0 mph initial test speed tolerance. The test efficiency benefits of such a small increase in initial vehicle speed tolerance would greatly outweigh what likely would be an immeasurably small impact on the test results.

Ambient Conditions

Section 1.3 the draft AEB Test Procedure limits conducting the tests to ambient temperature temperatures between 35 ºF and 104 ºF and wind speeds less than 11.2 mph. Those conditions are unnecessarily restrictive and would reduce the available days to conduct testing or waste precious test time waiting for conditions to change. Accordingly, NHTSA should modify the AEB Test Procedure to expand allowable temperatures down to 32 ºF and wind conditions up to and including 15 mph. Those minor changes will not adversely affect the results of the tests and would allow more efficient use of limited test resources.

Principal Other Vehicle (POV)

Section 1.4 of the draft AEB Test Procedure specifies a POV for the CIB tests that generally has characteristics representative of an actual vehicle. Such a general specification would allow testing with an extraordinarily wide variety of POVs, which may cause AEB systems to react differently. An AEB system may have greater or lesser confidence, and thus may react seconds sooner or later, based on the specific POV utilized for the testing. Such variability would make it challenging to compare AEB systems or vehicles if the testing was performed with different POVs. To ensure repeatable test results that can accurately compare the performance of different vehicles or different AEB systems, NHSTA should update the AEB Test Procedure to specify the target that was developed for the European New Car Assessment Program ("Euro NCAP"). Reference Attachment A, the *Euro NCAP Global Vehicle Target Specification*, Version 1.0, May 2018. The Euro NCAP target would provide more repeatable and comparable results from the AEB Test Procedure, with a relatively inexpensive and widely-utilized POV.

Data Collection

Vehicle Dimensions

Section 1.5 of the draft AEB Test Procedure includes a number of specifications that are identified as needed to measure performance and evaluate AEB system efficacy. Included is measuring the SV's XY-plane center of gravity. However, there does not appear to be any use of the center of gravity in the performance test procedures or measured results of the tests. Additionally, the center of gravity of a heavy truck is expensive and time-consuming to measure, and due to the customization and diversity of commercial vehicles nearly every one that is tested may need to be measured. Accordingly, we recommend that NHTSA omit the center of gravity measurement from the AEB Test Procedure.

Accelerator Pedal Force

Section 1.5 requires measuring the force applied to the SV's accelerator during the performance testing. Again, there does not appear to be any use of the pedal force in the performance test procedures or use of the pedal force data in the measured results of the tests. Measuring the accelerator pedal force requires non-trivial instrumentation and data recording and therefore the Agency should omit measuring the accelerator pedal force from the AEB Test Procedure.

Brake Temperature

Section 1.5 requires measuring the temperature of the brake shoe or pad during testing. To avoid confusion or unnecessary test burden, NHTSA should modify the AEB Test Procedure to refence the brake temperature measurement requirements in FMVSS No. 136, S6.3.11.

Crash Imminent Braking (CIB) Tests

Vehicle Loading

The AEB Test Procedure does not identify the proper loading of the SV when conducting the CIB tests. To ensure repeatable and comparable testing, truck tractors should be loaded to their rated GVWR. The AEB Test Procedure already specifies loading the vehicle to its GVWR to burnish the brakes, and we recommend carrying that loading over to the CIB tests that measure vehicle deceleration. Specifically, the AEB Test Procedure should follow the loading requirements in FMVSS No. 136, S6.3.3.1. To accomplish that loading, the tractor should be coupled with a control trailer. See, *id*. at S6.3.5. Please note that tractor loading is only necessary for the AEB tests that involve active braking, *i.e., the* Stopped Lead Vehicle (LVS), Slower Moving Lead Vehicle (LVM) and Decelerating Lead Vehicle (LVD) tests. Consistent with SAE J3029, any False Positive test may be conducted with the tractor in an unloaded condition, or “bobtail,” since the test would not measure any deceleration.

Number of Tests

The CIB test procedures in section 2.0 require conducting seven consecutive trials of each test. We believe that represents an unnecessarily large number of consecutive tests, the burden for which could be exacerbated by the excessively tight vehicle speed tolerance and time-consuming system reset requirements mentioned above. However, even if the Agency addresses those issues, seven consecutive tests still is excessive. AEB systems are sufficiently repeatable that not more than four consecutive tests are necessary to obtain an adequate sample size to assess the efficacy of the system. SAE J3029 specifies conducting each maneuver four times, and that is an appropriate number of test runs. To properly balance the amount of data produced and test efficiency, NHTSA should revise the CIB test requirements to specify no more than four consecutive trials.

LVD Headway

The Decelerating Lead Vehicle (LVD) test in section 2.4, with a 23m headway and both vehicles traveling at 55 km/h, is not reasonable for heavy trucks. The AEB system would need to command a full braking application to avoid the SV contacting the POV during the test, which is inappropriately aggressive. With a 23m headway and those speeds, the SV would contact the POV during every test, likely damaging both the SV and the POV. Accordingly, the Agency should revise the LVD test in section 2.4 to utilize a 32m headway. Additionally, to further improve the efficacy for the test for heavy trucks, the time for achieving POV longitudinal acceleration should be 2.0 ±0.1 seconds, instead of 1.5 ±0.1 seconds.

False Positive Tests

AEB systems encounter an infinite number of scenarios in use, and they must constantly differentiate between accident scenarios that warrant automatic braking and situations that do not. While manufacturers are continuously improving AEB systems to reduce unneeded brake applications, unfortunately a small number of false positive activations still happen. While we understand the desire for a test to show that a false positive AEB system activation will not happen, it is impossible to test for all potential false positive scenarios and therefore any test can only represent one of an infinite number of potential scenarios. Said differently, it is difficult to prove the negative. In the interest of test efficiency, the number of false positive tests should be minimized, and if the Agency still requires one, the test procedure should be as efficient and minimally burdensome as possible.

Considering the foregoing, at the very least NHTSA should eliminate the False Positive Evaluations -- Steel Trench Plate Test in section 2.5. Of the two false positive tests in the AEB Test Procedure, that is the most burdensome to conduct and it is the one least likely to produce consistent and repeatable results. Steel trench plates are expensive to procure and because they require machinery to move they are expense to utilize during testing. Additionally, curvature, thickness, and other properties of the steel trench plate can produce different results. If NHTSA believes that a false positive test is absolutely necessary, it should only retain in the AEB Test Procedure the Stationary Vehicles False Positive test in section 2.6. Additionally, if retained, the Agency should clarify that the stationary vehicles utilized for the test are passenger cars. As proposed the stationary vehicles in the test could be any of the myriad heavy trucks in the market and thus may negatively affect the repeatability and consistency of the test results.

Failure Detection Test

The draft AEB Test Procedure does not include a test of the system malfunction indicator. We believe before conducting any CIB test it would be prudent to ensure that the AEB system is functioning properly. Doing so is particularly important to determine that the system activation counter has not identified a fault, as discussed above. A simple failure detection test method is described in section 13 of SAE J3029 and we recommend that NHTSA add that test to the AEB Test Procedure.

Deactivation Test

For AEB systems that include the means to manually deactivate the system, it would be prudent to test whether the malfunction indicator lamp properly identifies that the system is deactivated. A simple deactivation test method is described in section 14 of SAE J3029, and we recommend that NHTSA add that test to the AEB Test Procedure.

Dynamic Brake Support (DBS)

According to section 3.1 of the AEB Test Procedure, DBS provides "supplemental braking when forward-looking sensors determine that driver-applied braking is insufficient to avoid an imminent crash with a lead vehicle." See, AEB Test Procedure, p. 16. We believe the DBS test is not appropriate for heavy trucks. All heavy truck AEB systems will apply the maximum level of braking that the system is programmed to provide to avoid or mitigate a crash, *regardless of the level of driver-applied braking*. That is, if the driver is not braking at all and the system detects an imminent collision, the AEB system will automatically apply the maximum level of braking that it is programmed to apply to avoid or mitigate the collision. Similarly, if in the same scenario the driver is applying the brakes but not hard enough to avoid the collision, the system will automatically increase the braking to achieve the same level as in the scenario where the drive applied no braking. In short, heavy truck AEB systems apply the maximum braking they are programmed to provide to avoid or mitigate a collision, *regardless of the level of braking being applied by the driver*.

Considering the foregoing, NHTSA should eliminate the DBS test in section 3.0 from the AEB Test Procedure. In addition to being unnecessary, it is an incredibly burdensome test that appears to be intended for passenger cars. Conducting the test requires a great deal of complicated instrumentation, data processing, and many test runs – all of which would be unreasonably burdensome for the high vehicle diversity and low production volumes of the heavy truck market. If there is a compelling reason to conduct the DBS test on heavy trucks, the Agency should at least devise an optional test method that utilizes a human test driver to apply the brakes instead of the advanced technologies needed to follow the AEB Test Procedure. Should the Agency insist on a DBS test for the heavy truck AEB Test Procedure, we stand ready to collaborate to devise an optional and less burdensome approach.

Conclusion

EMA looks forward to working with the Agency to refine the draft research test procedure titled *Test Track Procedures for Heavy-Vehicle Forward Collision Warning and Automatic Emergency Braking Systems.* Specifically, we would welcome the opportunity to conduct vehicle tests to the draft AEB Test Procedure to develop data to inform the Agency's finalization of the test procedure.

If there are any questions, or we could provide any additional information, please do not hesitate to contact Timothy Blubaugh at (312) 929-1972, or tblubaugh@emamail.org.

Respectfully submitted.

TRUCK & ENGINE
MANUFACTURERS ASSOCIATION

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Attachment A

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ASSESSMENT PROGRAMME

Technical Bulletin

Global Vehicle Target Specification

Version 1.0

May 2018
TB 025

Title	Global Vehicle Target Specification
Version	1.0
Document Number	TB025
Author	Euro NCAP Secretariat
Date	May 2018
Related Documents	AEB C2C Test Protocol, LSS Test Protocol
Status	Information
Application Date	May 2018

1 INTRODUCTION

Based on the outcome of the several Global Harmonization workshops organized by Euro NCAP, the National Highway Traffic Safety Administration (NHTSA), and the Insurance Institute for Highway Safety (IIHS), as well as the pre-studies from Dynamic Research, Inc. the following specification defines a 3-dimensional vehicle target called the Global Vehicle Target (GVT).

The Euro NCAP AEB C2C & LSS Test Protocols require the use of the Global Vehicle Target (GVT).

This document provides the technical specification for the GVT, which is designed to be an accurate surrogate for a passenger vehicle from almost any horizontal direction and in almost any conflict scenario while minimizing the potential for damage to the vehicle under test (VUT) and to minimize the risk to the VUT occupants.

All targets used for official Euro NCAP tests will meet these requirements, which are verified by the lab at the start of a test series.

1.1 Abbreviations

GVT	Global Vehicle Target
IR	Infrared
LiDAR	Light Detection And Ranging
LPRV	Low Profile Robotic Vehicle
PMD	Photonic Mixer Device
RADAR	Radio Detection And Ranging
RAM	Radar Absorbing Material
RCS	Radar Cross Section
VUT	Vehicle under test

2 VEHICLE TARGET

The GVT shall be comprised of representative vehicle attributes relevant to the target detection sensors used in the VUT. The required sensor-relevant GVT attributes for a system test are determined by the vehicle manufacturer and must be implemented in the manner specified in this document. The GVT must be detectable by following automotive sensors technologies: RADAR, Video, LiDAR, PMD, and IR.

1.1 Vehicle Target Features

The GVT representing a vehicle, whose purpose is to activate sensor systems, consists of a target structure and optionally a target carrier, representing a vehicle having the necessary features to be recognised from any direction (3D vehicle target).

and shall be lightweight and flexible so as to minimize the load imparted to the VUT body panels in the event of a collision. The GVT should also have radar-reflective and infrared-reflective materials that meet the specifications in sections 1.3 and 0.

The GVT shall provide a safe mounting location for a GPS antenna within the structure such that the radar reflective (i.e., metallic) fabric of the GVT does not interfere with the GPS satellite reception required by the robotic platform responsible for supporting, and moving when appropriate, the GVT during a VUT evaluation.

Figure 1: Global Vehicle Target

1.2 Vehicle Target Dimensions

The dimensions of the GVT provided in Tables 1 and 2 are shown in Figures 2 and 3, respectively. Note that the vertical measurements are based on a typical ground clearance of the motion platform of 20 mm.

Table 1: GVT Longitudinal and Vertical Dimensions

No.	Description	Dimension	Tolerance
1	Overall length	4023 mm	± 50 mm
2	Front ground clearance	173 mm	± 25 mm
3	Front skin height	488 mm	± 25 mm
4*	Hood height	290 mm	± 25 mm
5	Side ground clearance	185 mm	± 25 mm
6	Rear ground clearance	323 mm	± 25 mm
7	Overall height	1427 mm	± 50 mm
8	Tire diameter	607 mm	± 10 mm
9*	Front skin angle	6.4 deg	± 2.0 deg
10*	Rear skin angle	1.0 deg	± 0.5 deg
11	Hood length	792 mm	± 25 mm
12*	Side mirror position	1140 mm	± 25 mm
13	Side mirror length	229 mm	± 10 mm
14	Side mirror clearance	892 mm	± 25 mm
15	Side mirror height	132 mm	± 10 mm
16	Wheelbase	2565 mm	± 50 mm

* Optional reference measurements

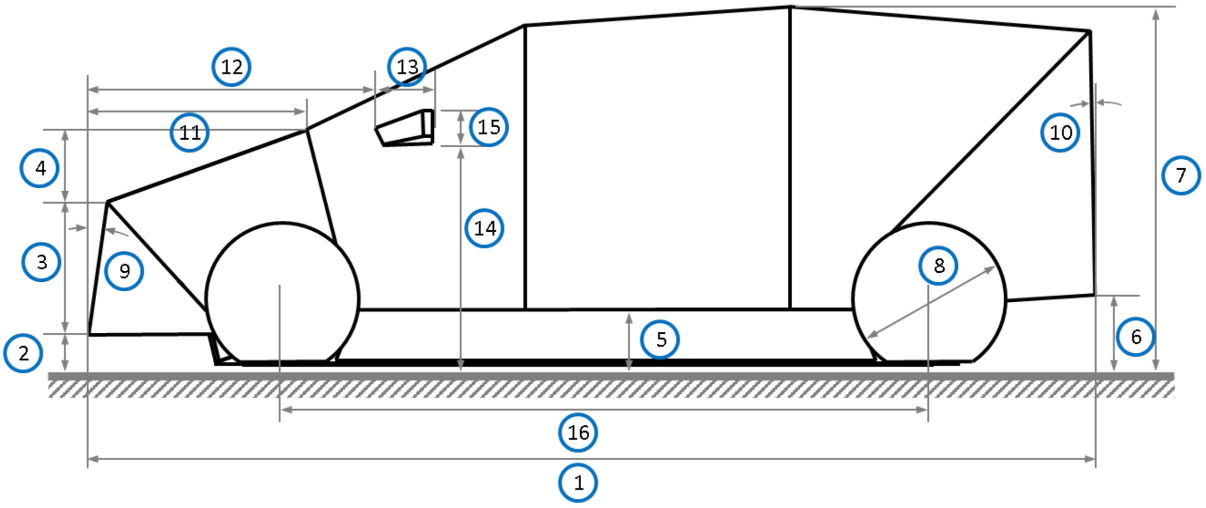

Figure 2: GVT Longitudinal and Vertical Dimensions

Table 2: GVT Lateral Dimensions

No.	Description	Dimension	Tolerance
1	Overall width (excluding mirrors)	1712 mm	± 50 mm
2	Roof width	1128 mm	± 50 mm
3	Overall width (including mirrors)	1798 mm	± 50 mm
4	Tire Width	206 mm	± 10 mm

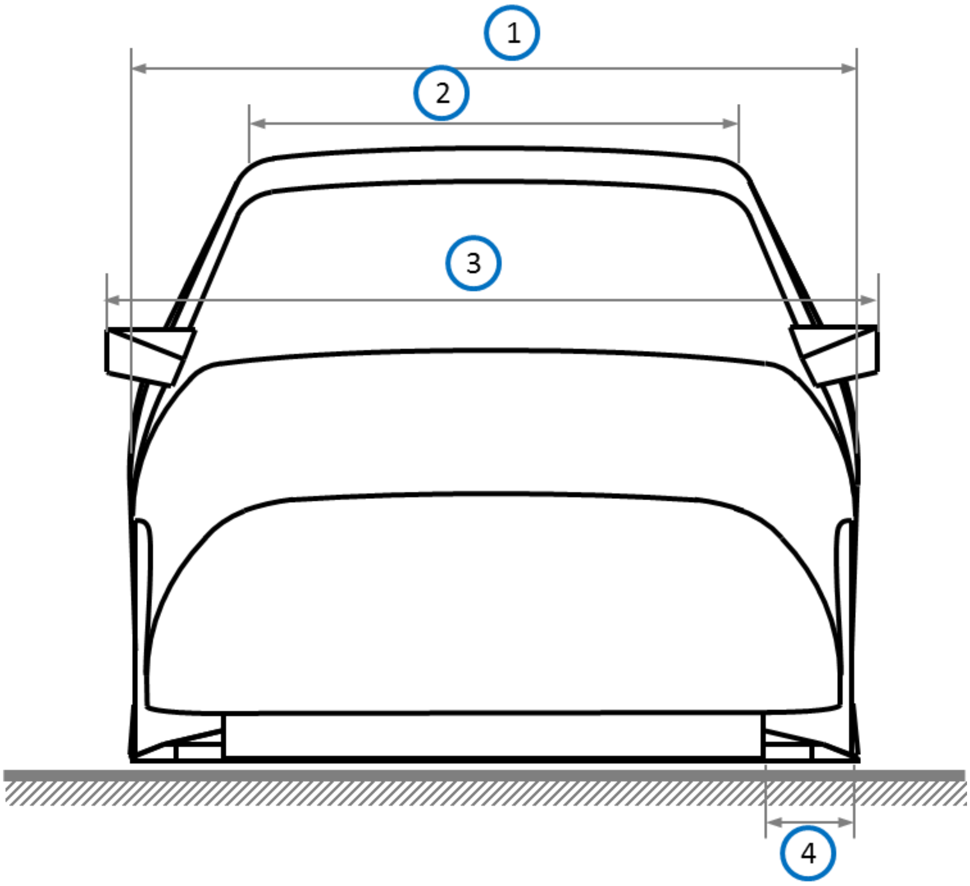

Figure 3: GVT Lateral Dimensions

1.3 Visible and Infrared Properties

Dimensionally, and from the perceptive of the sensors installed in the VUT, the GVT shall be representative of a white hatchback passenger vehicle. The IR reflectivity of the GVT surfaces, specified in Table 3, shall be in the wavelength range of 850 to 910 nm. Each of the visual areas of interest, as indicated in Figure 4, shall be measured in accordance with the procedure outlined in Appendix A1.

Figure 4: IR Areas of Interest

Table 3: IR Reflectivity

No.	Area of Interest	IR Reflectivity
1	White Vinyl (no graphics)	> 70%
2	Windshield, dark area	40% - 70%
3	Windshield, light area	> 70%
4	Side Mirror Face(1)	> 70%
5	Side Panel(1)	> 70%
6	Side Windows	> 70%
7	Tire, wall and tread(1)	10% - 40%
8	Rear bumper, black	< 10%
9	Rear window, light area	> 70%
10	Black fabric (RAM skirts, wheel wells)	< 10%

Note 1: Most of these objects have large variation in graphics. IR reflectivity should be averaged over many sampled areas.

1.4 Radar Properties

The radar reflectivity characteristics of the GVT shall be similar to a passenger vehicle of the same size.

1.4.1 Radar Cross Section (RCS)

The radar cross section of a vehicle may vary significantly with observation angle. Theoretically there is no RCS variation with the distance. However, due to the limited field of view of the radar sensor and the implemented free space loss compensation, the measured RCS significantly varies over distance, and in near distances the vehicle is not scanned over its complete height. The measured RCS is also influenced by geometrical effects (i.e., multi path with constructive and destructive interferences). Therefore, in this document RCS refers to the measured RCS by a given radar sensor with its specific parameter set, while recognizing that it does not necessarily correspond to the physical RCS. The method of measuring the GVT RCS is described in Appendix A2.

1.5 Mounting and Guidance System

Provisions must be made to ensure the GVT is fully supported and at the correct vertical height. Providing sufficient support is particularly critical for the wheel blocks which are relatively heavy and are located at the corners of the GVT footprint. In general, the following guidelines should be followed.

- All visible parts of the motion platform should be colored in grey.
- It must be ensured that the GVT mounting does not influence radar return. Where needed, RAM skirts shall be used to ensure the radar reflections from the motion platform are minimized.
- Reproducible positioning of the GVT is achieved by aligning the GVT with the motion platform mounting locations to within 2 cm.

1.6 Vehicle Target Weight and Collision Stability

- Maximum relative velocity of the VUT into the GVT: 120 km/h, (to prevent damage to the VUT).
- Maximum GVT weight: approximately 110 kg
- The GVT must continue to meet the specified requirements after repeated collisions.

APPENDIX

A1 Measurement of the IR reflectivity

The measurement of the GVT shall be made in accordance with the following procedure.

Required measurement equipment:

- A spectrometer capable of covering wavelengths from 850 to 910 nm, such as the Ocean Optics Flame-S-XR1 spectrometer (shown in Figure A1) or the Jaz Miniaturspektrometer,
- A light source
- A 45-degree probe
- A calibration standard

The spectrometer should be calibrated using the calibration procedure specified by the device manufacturer. The calibration shall then be confirmed using a calibration standard with a known reflectivity.

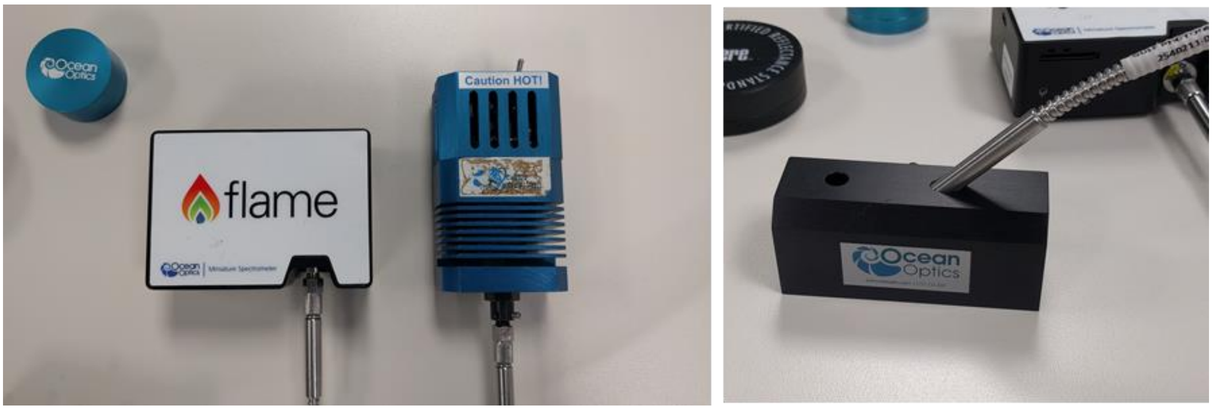

Figure A1. IR Measurement Equipment

The IR measurements shall be taken at three locations for each feature to be measured, and shall be averaged across the three measurements for wavelengths in the range of 850 to 910 nm.

Figure A2 and Figure A3 show the averaged results for the various areas of interest, which are listed in Table 3 (previously shown in Section 1.3).

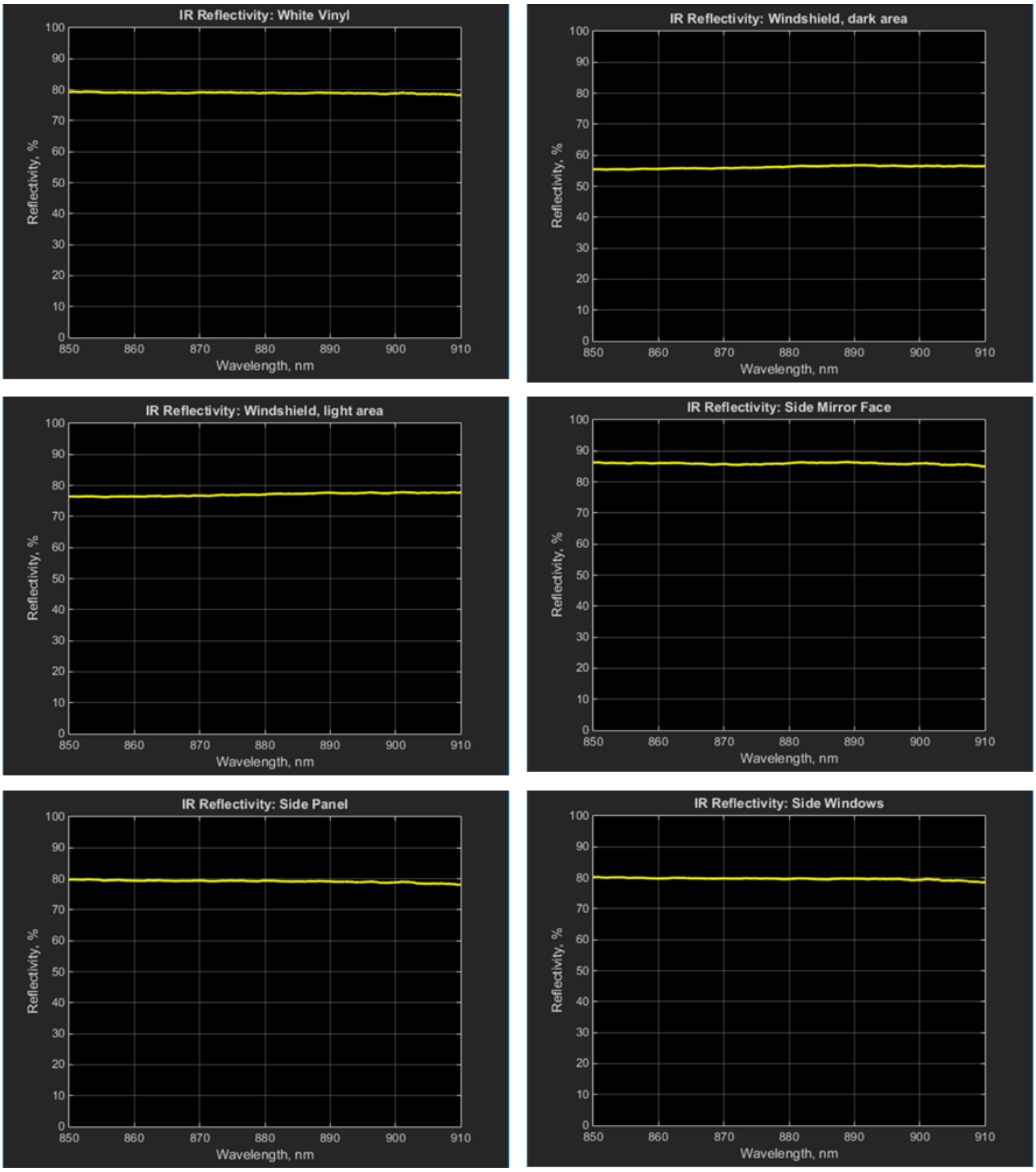

Figure A2. Example IR Measurements (1-6)

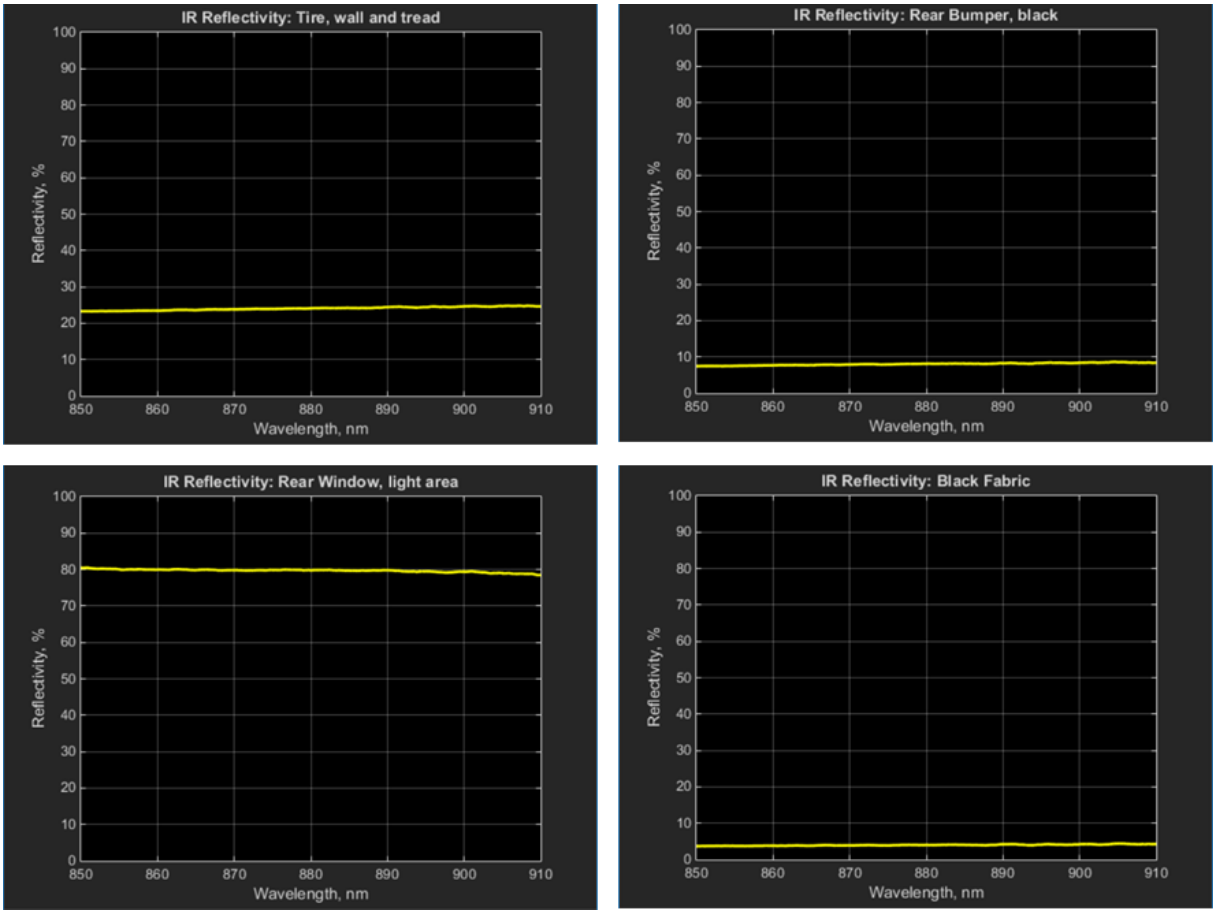

Figure A3. Example IR Measurements (7-10)

A2 Measurement of Radar Reflectivity

Measuring RCS at a fixed distance can produce misleading results because the sensor might be experiencing either cancellation or amplification due to the multi-path effect. Therefore, it is necessary to measure RCS by moving the sensor towards the object, such that the sensor will be moving into and out of the cancellation and amplification regions. Also, to reproduce the effect of decreasing RCS at close range, the radar reflectivity of the GVT must be distributed over the whole body causing the RCS to decrease at shorter distances due to partial visibility of the GVT by the sensor. The method of measuring the GVT RCS is described in Appendix A2.

The instantaneous measured RCS of a vehicle or target can experience cancellation due to the radar multi-path effect at various ranges. These cancellation regions will result in very low RCS relative to the typical RCS at certain distances (see examples in Appendix A3). Reducing the lower RCS boundary to account for these cancellation regions could allow for a target with a low average RCS to be deemed acceptable. Therefore, the RCS of the GVT is specified using a curve fit to the measured RCS data as a function of range, as well as tolerance bounds on the curve fit.

The RCS curve fit characterizes both the far-field RCS and the near-field RCS which, as noted above, decreases with range. The form of the curve fit RCS, as shown in Figure 4, is:

$$RCS_{FIT} = RCS_{FAR} - K_{DEC} \text{ x } \min(R - R_{FAR}, 0)^2 \qquad \text{where } K_{DEC} \geq 0$$

The RCS curve fit is calculated by determining the parameters, RCS_{FAR} and K_{DEC}, such that the sum of the square of errors between the RCS curve fit and the raw RCS data is minimized. The parameter R_{FAR} is dependent on several factors, including the sensor parameters. For this analysis it is assumed to be fixed for a given sensor.

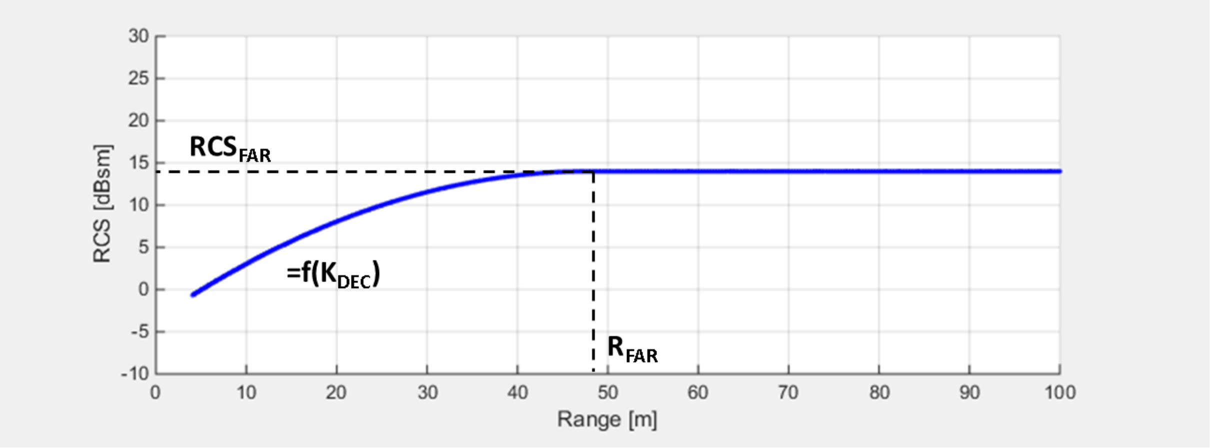

Figure 4: Form of the Average RCS Curve

The RCS curve fit of the GVT should stay within a defined range, defined by upper and lower bounds. For the GVT, the equations defining the bounds are given below for a Bosch LRR3 sensor and a Continental ARS 408-21 sensor, using the calibration and measurement methods described in Appendix A2.

$RCS_{BOUNDS,BOSCH} = 16 - 0.004 \times \min(R - 48,0)^2 \pm 6$ for the Bosch sensor

$RCS_{BOUNDS,CONTI} = 16 - 0.015 \times \min(R - 34,0)^2 \pm 6$ for the Continental sensor

A slightly different definition must be made for each frequency and sensor variant since the RCS reduction at close range is a function of the sensor parameters.

Depicted in Figure 6 are the RCS boundaries for measurements with these two commercially available 77 GHz sensors. If other sensors are used or the mounting position deviates from that described in Appendix A2 or the test surface differs from the description in this appendix, other RCS values may be obtained. In that case an additional verification/adaption of the boundaries (Figure 6) may be necessary for validation of the GVT. These boundaries are valid for a rear approach measurement from 180 degrees with 100% overlap.

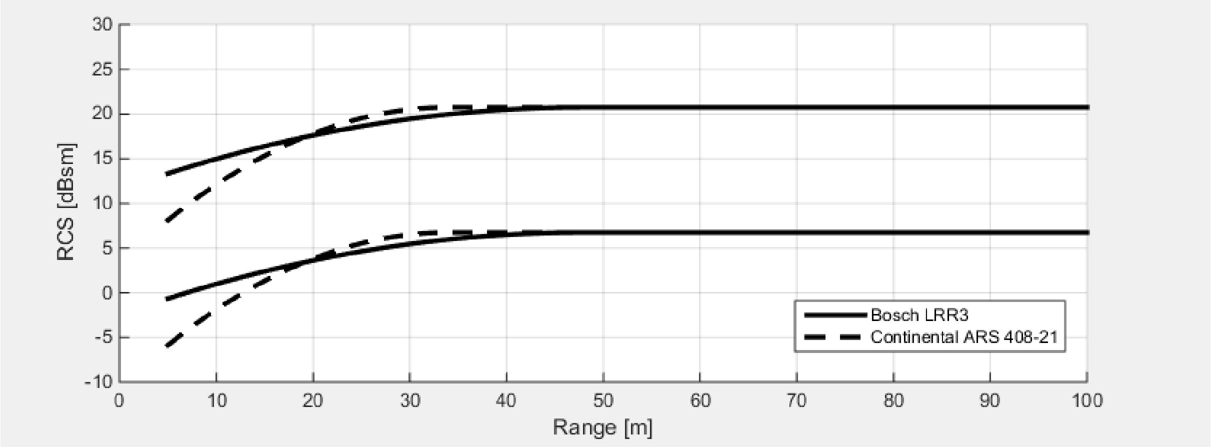

Figure 5: Vehicle target RCS boundaries for measurements at 77GHz

Radar reflectivity measurement of the GVT shall be made in accordance with the following procedure.

Recommended Measurement Setup

A reference measurement with a corner reflector calibrated to 10 dBsm is required. The corner reflector shall be positioned at a vertical height of 500 mm +/- 10mm. The average RCS, calculated as the median RCS in m^2 but reported in decibels per square-meter, shall be used to calculate the correction factor to be applied to the output of the sensor as needed.

Sensor Configuration and Orientation

- 77 GHz wavelength with performance similar to either of the following:
  - Bosch LRR3
  - Continental ARS 408-21
- Vertical height above the ground: 500 mm +/- 25mm
- Horizontal alignment: +/-1 deg to center line
- Vertical alignment: +/-1 deg to center line

Sensor Motion Device

The radar sensor shall be moved towards the object being measured (i.e., the corner reflector reference or GVT). The sensor may be attached to a vehicle or to a specialized measurement cart (e.g., like that shown in Figure A4). Alternatively, the GVT could be moved towards a static sensor, as long as the relative motion between the sensor and GVT is the same as the specified scenario. In any case, the requirements below are applicable:

- Angular deviation (relative to the direction of motion): <0.5 deg
- Positioning measurement accuracy (longitudinal/lateral): < 50 mm

Figure A4. Example Radar Measurement Cart

Vehicle Target

- Positioning accuracy (longitudinal/lateral): < 20 mm
- Angular orientation deviation (relative to direction of sensor motion): < 1 deg

Test Environment

- No additional objects/buildings in the area indicated as “Free space” in Figure A5
- Proving ground surface completely covered with tarmac, asphalt, or concrete and completely flat within 5m of the path of the sensor or GVT
- Ground conditions: flat and dry
- No metallic or other strong radar-reflecting parts within the area indicated as “Free space” in Figure A5

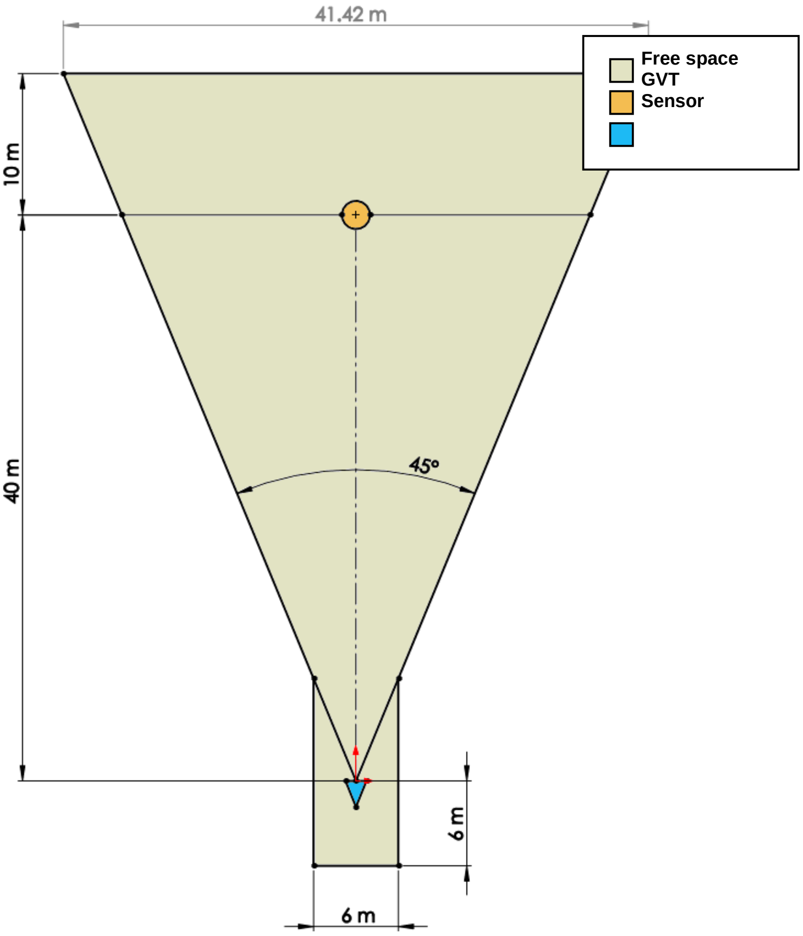

Figure A5: Test Environment

<u>Measurement Scenario</u>

- Static GVT with moving measurement device
- Initial distance: 100 m to 5m
- Approaching speed: 3-5 km/h
- Approach aspect: 180 deg (i.e., the sensor faces the rear of a static GVT)
- Perform 3 approaches

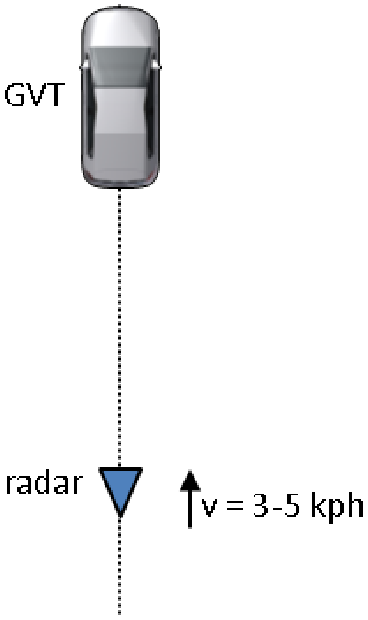

Figure A6: Measurement Scenario

Data Analysis

During each of the three approach measurements, the range and RCS of the GVT shall be recorded. The curve-fit RCS shall then be calculated by minimizing the sum-squared error, E_{SS}, between the raw RCS data and the curve-fit RCS. In other words, the parameters RCS_{FAR} and K_{DEC} shall be optimized to find the solution that minimizes the error term E_{SS}, where

$$E_{SS} = \sum(RCS_{AVG}(R) - RCS_{MEAS}(R))^2$$

$$RCS_{FIT}(R) = RCS_{FAR} - K_{DEC} \text{ x } \min(R - R_{FAR}, 0)^2 \qquad (K_{DEC} \geq 0)$$

Note: As a point of reference, the R_{FAR} values for the sensors previously described in **Sensor Configuration and Orientation** are as follows:

- Bosch LRR3: 48 m
- Continental ARS 408-21 : 34 m

A3 RCS Measurement Examples

The example data in this appendix were measured during the GVT Familiarization event, hosted by Thatcham Research in Upper Heyford, United Kingdom on 12-13 April 2018.

Figure A7 provides an RCS measurement example of the calibration measurement (10 dBsm trihedral) for the Bosch LRR3 and Continental ARS 408-21 sensors. The depicted data has been scaled based on the known RCS of the measured object.

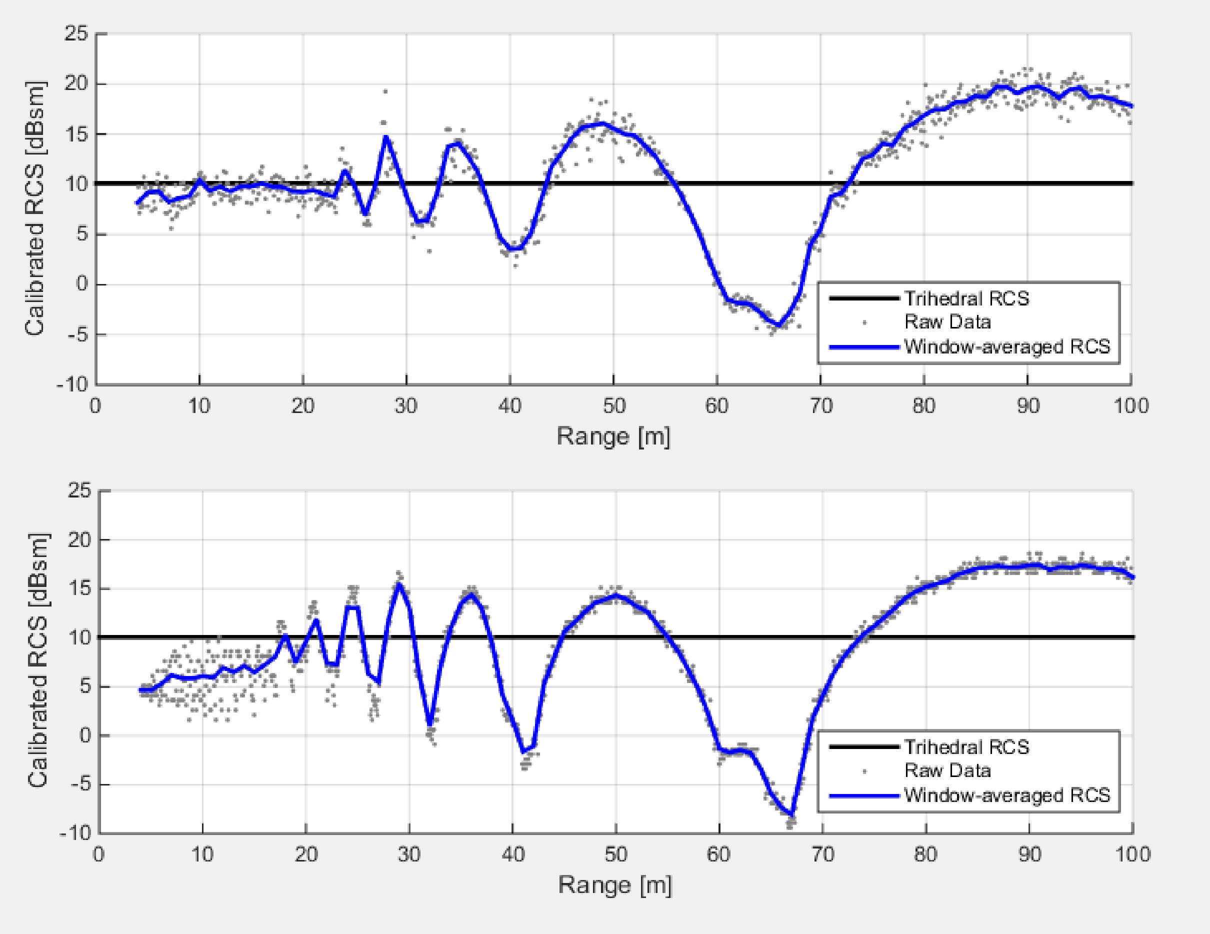

Figure A7: Example RCS measurement of trihedral calibration object using the Bosch (top) and Continental (bottom) sensors

Figures A8 through A10 provide RCS measurement examples for the GVT using the evaluation methodology defined in Appendix A2 for the Bosch LRR3 and Continental ARS 408-21 sensors, respectively. The raw data depicted in the figures below were captured during three measurement scenarios.

Figure A8 provides an example RCS measurement of the GVT on a robotic platform. Figure A9 provides an example RCS measurement of the GVT on a foam stand used for static test scenarios. Figure A10 provides an example RCS measurement of the previous version (Revision E) GVT with a Retrofit Kit. The Retrofit Kit is designed to ensure the radar characteristics of the Revision E GVT are similar to the latest GVT.

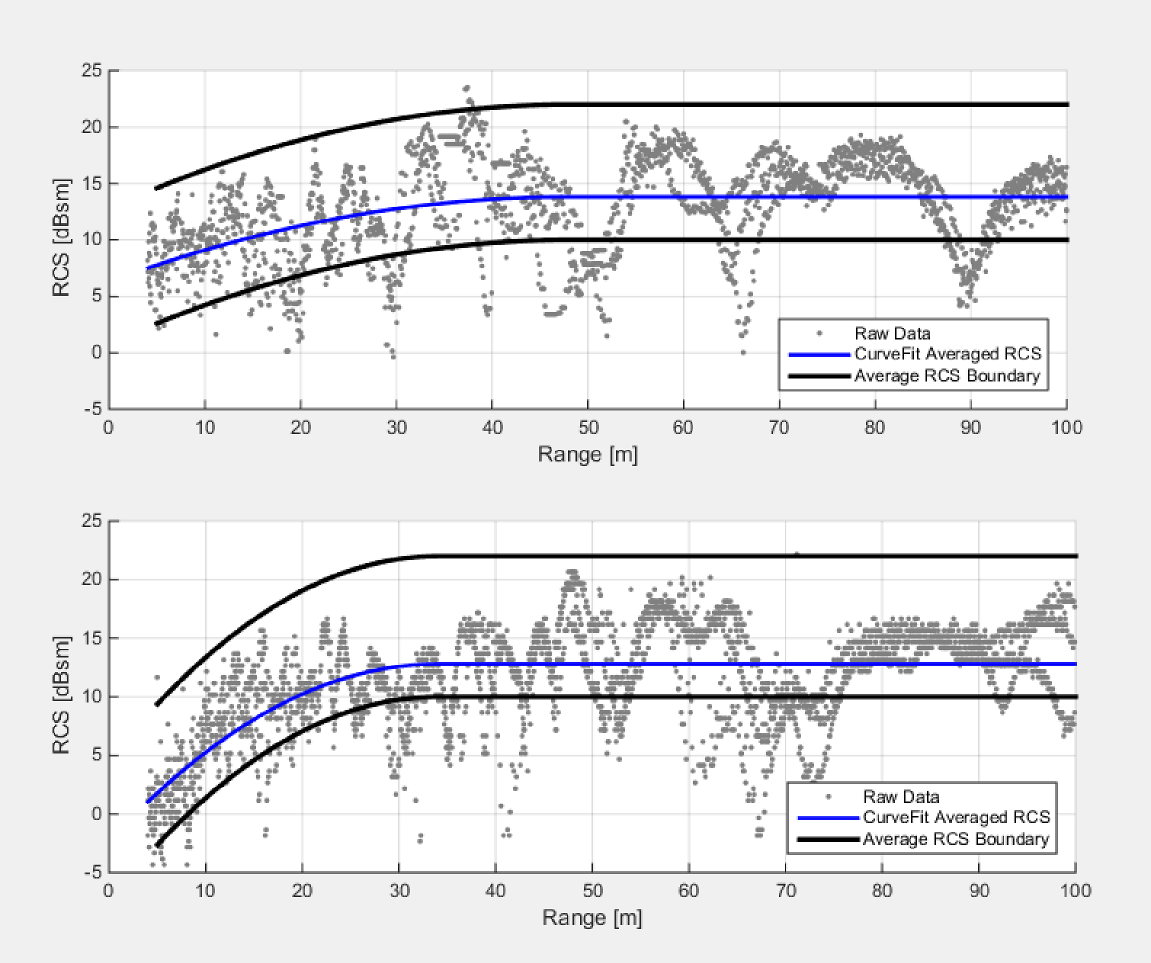

Figure A8: Example RCS measurement of GVT on Platform using the Bosch (top) and Continental (bottom) sensors

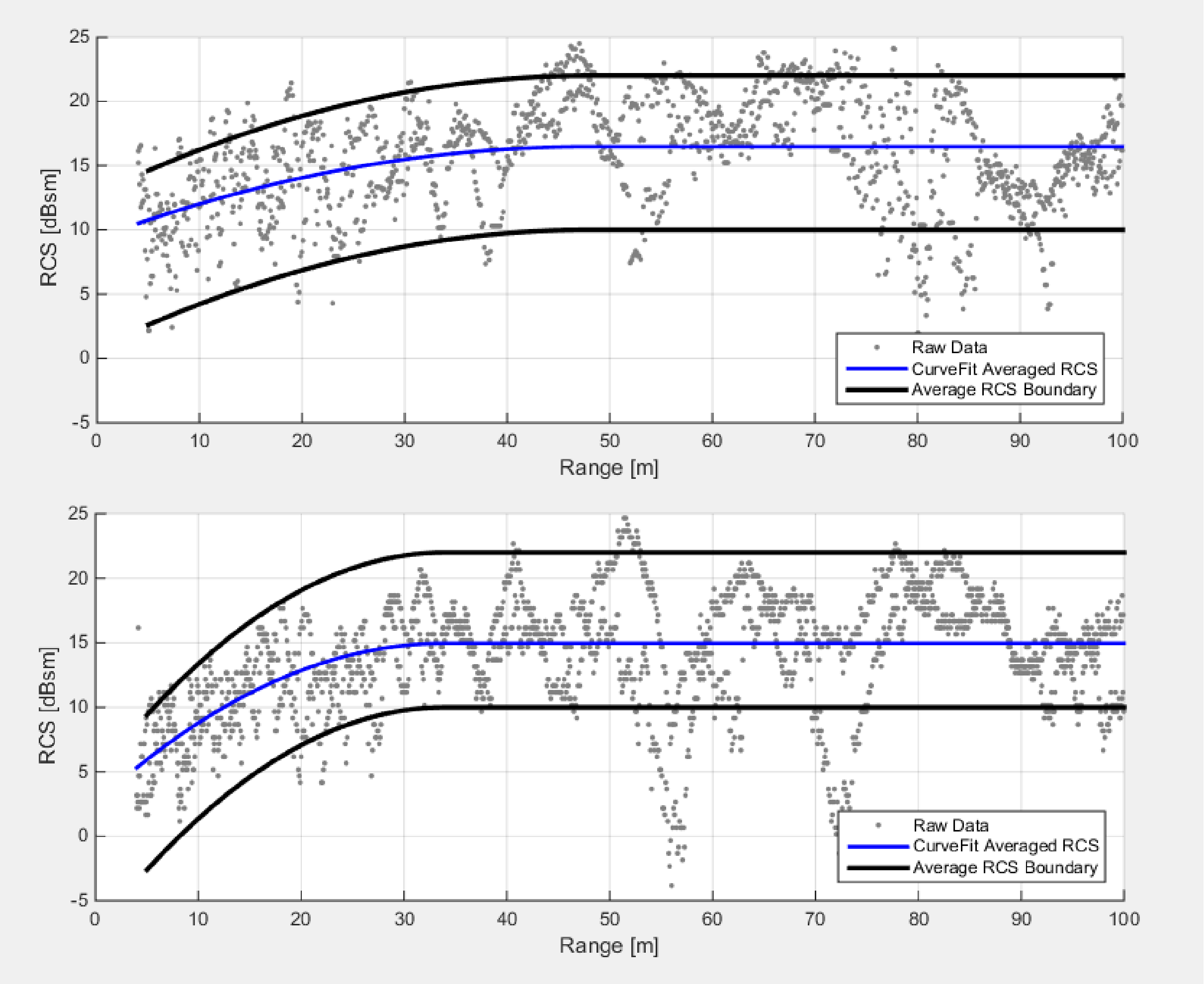

Figure A9: Example RCS measurement of GVT on Foam Stand using the Bosch (top) and Continental (bottom) sensors

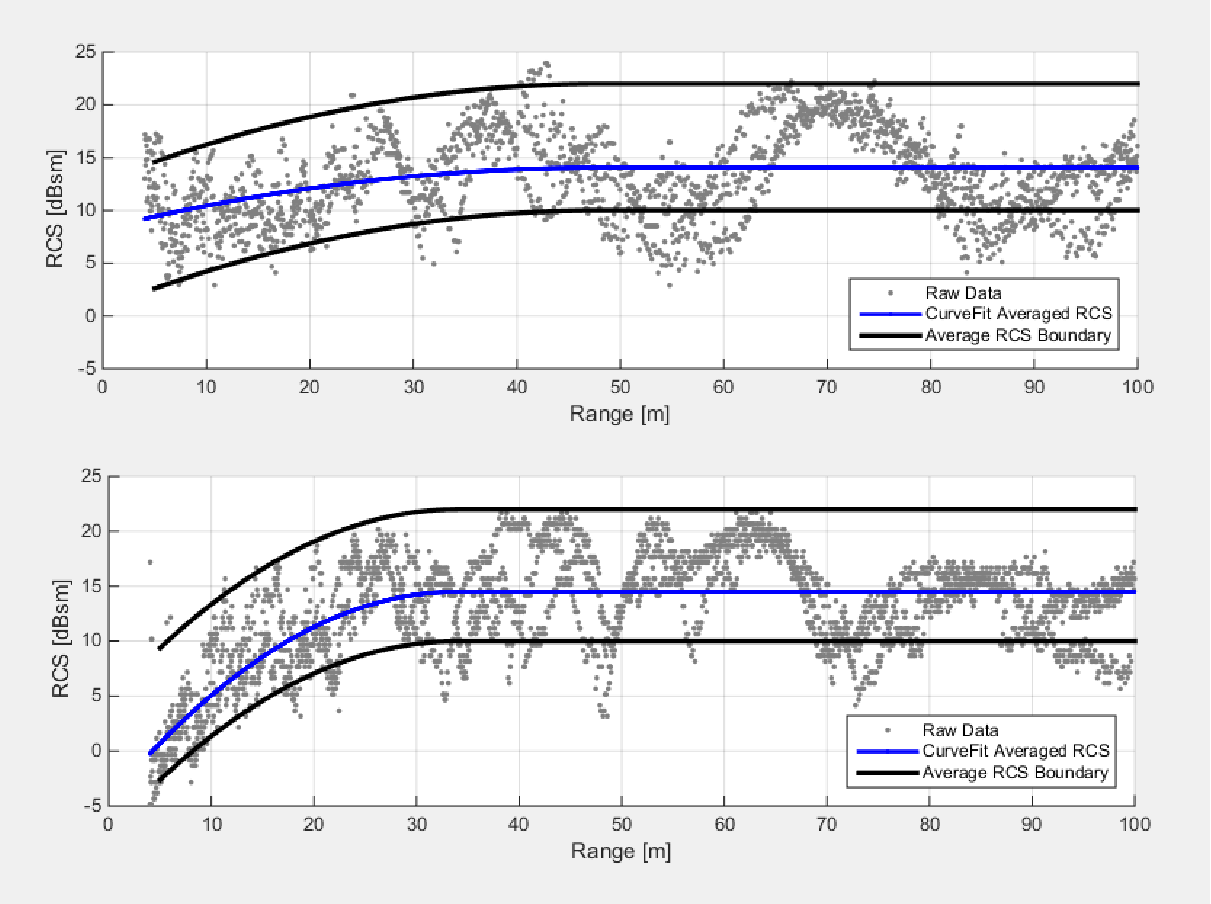

Figure A10: Example RCS measurement of GVT (Revision E with Retrofit Kit) on Platform using the Bosch (top) and Continental (bottom) sensors