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Camera Monitor Systems
Test Protocols and Performance Requirements

RATIONALE

To address demands for increased blind spot coverage and improving rearward indirect visibility by replacing rearview mirrors with camera monitor systems (CMS). CMS can offer wider and taller field of view coverage rearward of the vehicle in daytime, nighttime, and in varying weather and environmental conditions and can offer increased situational awareness to the vehicle operator. Additionally, replacing rearview mirrors with CMS can improve direct sideways vision, reduce neck rotation angle, and improve energy efficiency.

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1. SCOPE

This SAE Recommended Practice provides test protocols with performance requirements for camera monitor systems (CMS) to replace existing statutorily required inside and outside rearview mirrors for U.S. market road vehicles.

This practice expands specific technical content while retaining harmonization with the FMVSS 111 rear visibility standard and other international standards.

This is accomplished by defining required roadway fields of view as specific fields of view (FOV) displayed inside the vehicle. Specific testing protocols and/or specifications are added to enhance ease of use using straightforward language, and any specifications are intended to be independent of different camera and display technologies unless otherwise explicitly stated.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 1-877-606-7323 (U.S. and Canada only) or 1-724-776-4970 (outside U.S. and Canada), www.sae.org.

SAE J941 Motor Vehicle Drivers' Eye Locations

SAE J1050 Describing and Measuring the Driver's Field of View

SAE J1757-1 Standard Metrology for Vehicular Displays

Forbes, L., Farber, E., Swigart, T., and Jack, D., "Field of View from Automotive Vehicles," SP-381, 1973. National Automobile Engineering Meeting, Detroit, MI, 1973, May 14-18.

Platzer, G., "The Geometry of Automotive Rearview Mirrors - Why Blind Zones Exist and Strategies to Overcome Them," SAE Technical Paper 950601, 1995, https://doi.org/10.4271/950601.

2.1.2 ISO Publications

Copies of these documents are available online at www.iso.org/store.

ISO 9241-305:2008 Ergonomics of Human-System Interaction - Part 305: Optical Laboratory Test Methods for Electronic Visual Displays

ISO 16505:2019 Road Vehicles - Ergonomic and Performance Aspects of Camera Monitor Systems - Requirements and Test Procedures

2.1.3 NHTSA Publications

Available from National Highway Traffic Safety Administration, 1200 New Jersey Avenue SE, West Building, Washington, DC 20590, Tel: 1-888-327-4236, www.nhtsa.gov.

FMVSS 111 Rear Visibility

TP-111V-01 Laboratory Test Procedure for FMVSS 111 - Rear Visibility (Other than School Buses)

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2.1.4 UMTRI Publications

Copies of these documents are available online at https://deepblue.lib.umich.edu/documents.

Reed, M.P., Ebert, S.M., and Flannagan, M.J. (2001). *Mirror field of view in light trucks, minivans and sport utility vehicles* (Report No. UMTRI-2001-1). University of Michigan Transportation Research Institute.

Reed, M.P., Lehto, M.M., and Flannagan, M.J. (2000). *Field of view in passenger car mirrors* (Report. No. UMTRI-2000-23). University of Michigan Transportation Research Institute.

2.1.5 UN Publications

Copies of these documents are available online at https://digitallibrary.un.org/.

Regulation No. 46 Uniform provisions concerning the approval of devices for indirect vision and of motor vehicles with regard to the installation of these devices

2.1.6 Other Publications

Boyce, P.R. (2003). *Human factors in lighting* (2nd ed.), p. 585. Taylor & Frances.

Steinkuller, P.G. (2010). Legal vision requirements for drivers in the United States. *AMA Journal of Ethics*, *12*(12), 938-940.

Driver Focus–Telematics Working Group. (2006). *Statement of principles, criteria and verification procedures on driver interactions with advanced in-vehicle information and communication systems — 2006 update*. Alliance of Automobile Manufacturers, Washington, DC.

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Recommended Practice.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 1-877-606-7323 (U.S. and Canada only) or 1-724-776-4970 (outside U.S. and Canada), www.sae.org.

SAE J670 Vehicle Dynamics Terminology

SAE J1750 Describing and Evaluating the Truck Driver's Viewing Environment

SAE J1757-2 Standard - Optical System for HUD Automotive

de Vos, A., van der Horst, R., and Perel, M., "Non-planar Rearview Mirrors: The Influence of Experience and Driver Age on Gap Acceptance and Vehicle Detection," SAE Technical Paper 2001-01-0321, 2001, https://doi.org/10.4271/2001-01-0321.

Flannagan, M., Sivak, M., and Traube, E., "Quantifying the Direct Field of View when Using Driver-Side Rearview Mirrors," SAE Technical Paper 1999-01-0656, 1999, https://doi.org/10.4271/1999-01-0656.

Flannagan, M., "Current Status and Future Prospects for Nonplanar Rearview Mirrors," SAE Technical Paper 2000-01-0324, 2000, https://doi.org/10.4271/2000-01-0324.

2.2.2 GSO Publications

Copies of these documents are available online at www.gso.org.sa/store.

GSO 422:2005 Cars - Rearview Mirrors

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2.2.3 ISO Publications

Copies of these documents are available online at www.iso.org/store.

ISO 15008 Road Vehicles - Ergonomic Aspects of Transport Information and Control Systems - Specifications and Test Procedures for In-Vehicle Visual Presentation

2.2.4 NHTSA Publications

Available from National Highway Traffic Safety Administration, 1200 New Jersey Avenue SE, West Building, Washington, DC 20590, Tel: 1-888-327-4236, www.nhtsa.gov.

TP-111V-00 Laboratory Test Procedure for FMVSS 111 - Rearview Mirrors (Other than School Buses)

De Vos, A.P. (2000). *Non-planar driver's side rearview mirrors: A survey of mirror types and European driver experience and a driver behavior study on the influence of experience and driver age on gap acceptance and vehicle detection* (Report No. DOT HS 809 149), p. 106. National Highway Traffic Safety Administration.

Fitch, G.M., Camden, M.C. Olsen, R.L., McClafferty, J., Morgan, J.F., Wharton, A.E., Howard, H.E., Trimble, T., and Hanowski, R.J. (2011). *Field demonstration of heavy vehicle camera/video imaging systems: Final report* (Report No. DOT HS 811 475), p. 524. National Highway Traffic Safety Administration.

Kelley, C.R. and Prosin, D.J. (1969). *Motor vehicle rear vision: Final report* (Contract No. FH-11-6951). National Highway Traffic Safety Administration.

Mazzae, E.N., Baldwin, G.H.S., and Andrella, A.T. (2018). *Examination of a prototype camera monitor system for light vehicle outside mirror replacement* (Report No. DOT HS 812 582). National Highway Traffic Safety Administration.

Wierwille, W.W., Schaudt, W.A., Blanco, M., Alden, A.S., and Hanowski, R.J. (2011). *Enhanced camera/video systems (E-C/VISs) for heavy vehicles: Final report* (Report No. DOT HS 811 483). National Highway Traffic Safety Administration.

Wierwille, W.W., Schaudt, W.A., Gupta, S., Spaulding, J.M., Bowman, D.S., Fitch, G.M., Wiegand, D.M., and Hanowski, R.J. (2008). *Study of driver performance/acceptance using aspheric mirrors in light vehicle applications*: *Final report* (Report No. DOT HS 810 959). National Highway Traffic Safety Administration.

Wierwille, W.W., Schaudt, W.A., Gupta, S.K., Spaulding, J.M., and Hanowski, R.J. (2008). *Development of a performance specification for camera/video imaging systems on heavy vehicles, specifications* (Report No. DOT HS 810 958). National Highway Traffic Safety Administration.

Wierwille, W.W., Schaudt, W.A., Spaulding, J.M., Gupta, S.K., Fitch, G.M., Wiegand, D.M., and Hanowski, R.J. (2008). *Development of a performance specification for camera/video imaging systems on heavy vehicles, supporting research* (Report No. DOT HS 810 960). National Highway Traffic Safety Administration.

2.2.5 TMC Publications

Available from Technology and Maintenance Council of American Trucking Associations, 80 M Street, Suite 800, Washington, DC 20003, Tel: 703-838-1763, https://tmc.trucking.org/.

TMC RP 428A Guidelines for Vision Devices

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2.2.6 UMTRI Publications

Copies of these documents are available online at https://deepblue.lib.umich.edu/documents.

Flannagan, C.A.C., Balint, A., Klinich, K.D., Sander, U., Manary, M.A., Cuny, S., McCarthy, M., Phan, V., Wallbank, C., Green, P.E., Sui, B., Forsman, A., and Fagerlind, H. (2015). *Comparing motor-vehicle crash risk of EU and US vehicles* (Report No. UMTRI-2015-1). University of Michigan Transportation Research Institute.

Luoma, J., Flannagan, M.J., and Sivak, M. (2000). *Effects of nonplanar driver-side mirrors on lane change crashes* (Report No. UMTRI-2000-26). University of Michigan Transportation Research Institute.

Schumann, J., Sivak, M., and Flannagan, M.J. (1996). *Are driver-side convex mirrors helpful or harmful?* (Report No. UMTRI-96-7). University of Michigan Transportation Research Institute.

2.2.7 UN Publications

Copies of these documents are available online at https://digitallibrary.un.org/.

Regulation No. 125 Uniform provisions concerning the approval of motor vehicles with regard to the forward field of vision of the motor vehicle driver

2.2.8 Other Publications

Large, D.R., Crundall, E., Burnett, G., Harvey, C., and Konstantopoulos, P. (2016). Driving without wings: The effect of different digital mirror locations on the visual behaviour, performance and opinions of drivers. *Applied Ergonomics*, *55*, 138-148. https://doi.org/10.1016/j.apergo.2016.02.003.

Schmidt, E.A., Hoffmann, H. Krautscheid, R., Bierbach, M., Frey, A., Gail, J., and Lotz-Keens, C. (2015). *Final report: Camera-monitor systems as a replacement for exterior mirrors in cars and trucks*. Federal Highway Research Institute (BASt).

Terzis, A. (Ed.) (2016). *Handbook of camera monitor systems: The automotive mirror-replacement technology based on ISO 16505*. Springer.

3. DEFINITIONS

FIELD OF VIEW BOUNDING RECTANGLE: Rectangular subset of an active display area with boundaries oriented along display pixel rows and columns, respectively. The boundaries are chosen to be tangential to the minimum required field of view (FOV) under consideration.

4. TESTS

4.1 Driver Vision - Vehicle Performance Tests

4.1.1 Field of View - Passenger Cars

4.1.1.1 Outside Rearview CMS - Driver's Side Field of View

4.1.1.1.1 Outside Rearview CMS - Driver's Side Field of View Requirement

The driver's outside rearview camera monitor system (CMS) shall provide the driver with a view of a level road surface extending to the horizon from a line, perpendicular to a longitudinal plane tangent to the driver's side of the vehicle at the widest point, extending 2.4 m out from the tangent plane 10.7 m behind the driver's eyes, with the seat in the rearmost position, when the vehicle is occupied by the driver and four passengers or the designated occupant capacity. The field of view may be partially obscured by rear body or fender contours.

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The location of the driver's eye reference points shall be the SAE J941 for CAD-based verifications and the FMVSS 111 RVC for physical test verifications.

NOTE 1: The field of view of the driver's outside rearview CMS should cover at least the minimum field of view for a conventional driver's outside mirror.

NOTE 2: The camera view and its location will be a trade-off between camera height and depth perception.

NOTE 3: To avoid an unnatural driving perspective, a low camera mounting location should be avoided; see Appendix A.

4.1.1.1.2 Outside Rearview CMS - Driver's Side Field of View Verification Test - CAD Evaluation

Method A

The CMS field of view can be evaluated through CAD by creating a triangular region based on the eye-point projection. The height of the triangular region is determined by choosing a horizon point (e.g., 150 m) and projecting to the plane at 10.7 m behind the driver's eyes along the sight line from the vehicle's eye point projected to the longitudinal plane tangent to the driver's side of the vehicle at the widest point. The triangular region can then be evaluated from the camera's entrance pupil as defined in CAD according to the designed position and viewing angles.

Method B

Alternatively, the CMS field of view can be evaluated through CAD by creating a triangular region based on the height of the CMS camera entrance pupil when attached to the vehicle. The height of the triangular region is determined by choosing a horizon point (e.g., 150 m) and projecting to the plane at 10.7 m behind the driver's eyes along the sight line from the vehicle's CMS camera entrance pupil projected to the longitudinal plane tangent to the driver's side of the vehicle at the widest point. The triangular region can then be evaluated from the camera's entrance pupil as defined in CAD according to the designed position and viewing angles.

CAD Evaluation Procedure

1. Generate CAD-based targets depicting the outside rearview CMS - driver's side field of view.

2. Generate CAD representations of the outside rearview CMS - driver's side cameras' field of view.

3. Verify and record the result, showing that the views captured by the camera design are capable of fully displaying the outside rearview CMS - driver's side field of view.

4.1.1.1.3 Outside Rearview CMS - Driver's Side Field of View Verification Test - Physical Test

Physical Test Procedure

The outside rearview CMS - driver's side field of view can be evaluated through a physical test according to the following procedure:

1. Maneuver the vehicle onto a predetermined location on the level floor of the test laboratory.

2. Establish a vertical longitudinal plane tangent to the widest point of the test vehicle on the driver's side (parallel to the centerline of the vehicle) and locate its intersection with the floor.

3. Measure 10.7 m (35 feet) to rear of the driver's eye location and set up a field-of-view test screen perpendicular to the tangent plane.

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4. Load the vehicle to simulate the driver and four passengers (unless capacity is less) with ballast of 68 kg (150 pounds) per occupant.

5. Block and secure the vehicle in place to eliminate vertical or horizontal motion during the test.

6. Mark the edges of the outside rearview CMS - driver's side field of view using tape, paint, or any other acceptable means.

Method A

For Method A, calculate the height of A assuming a horizon of not less than 150 m (e.g., A = eye-point height x [150 - 10.7] / 150); see Figure 1.

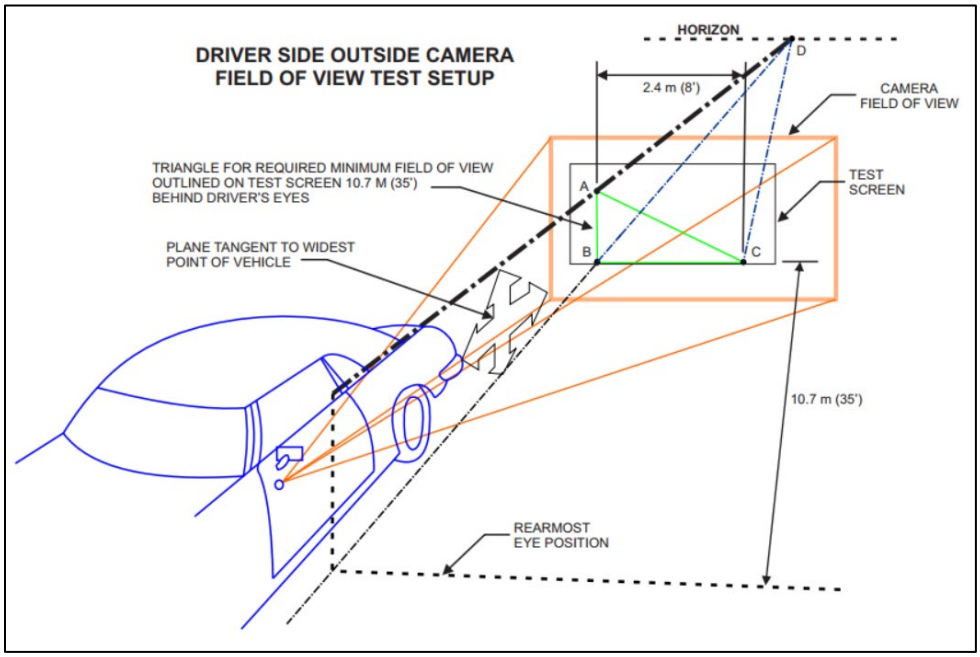


Figure 1 - Verification test - Method A, physical test

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Method B

For Method B, calculate the height of A assuming a horizon of not less than 150 m (e.g., A = camera entrance pupil height x [150 - 10.7 + X_{cam}] / 150), where X_{cam} is the camera position in X relative to the eye-point position in X and is positive if the camera is positioned forward of the eye-point in the longitudinal direction; see Figure 2.

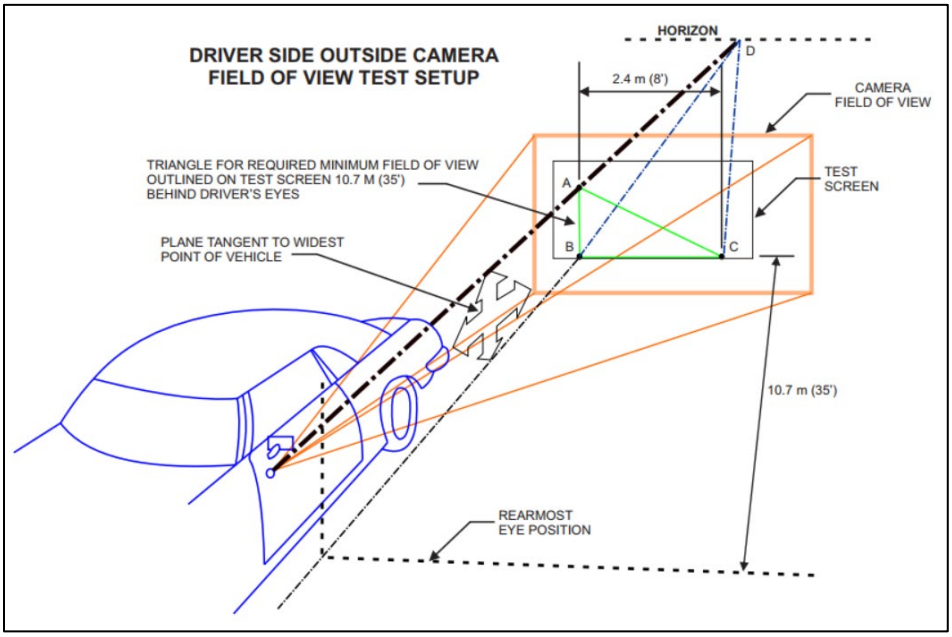


Figure 2 - Verification test - Method B, physical test

A comparison of Method A and Method B physical tests is shown in Figure 3. Note the difference in the projection line passing through A to D. See Appendix A.

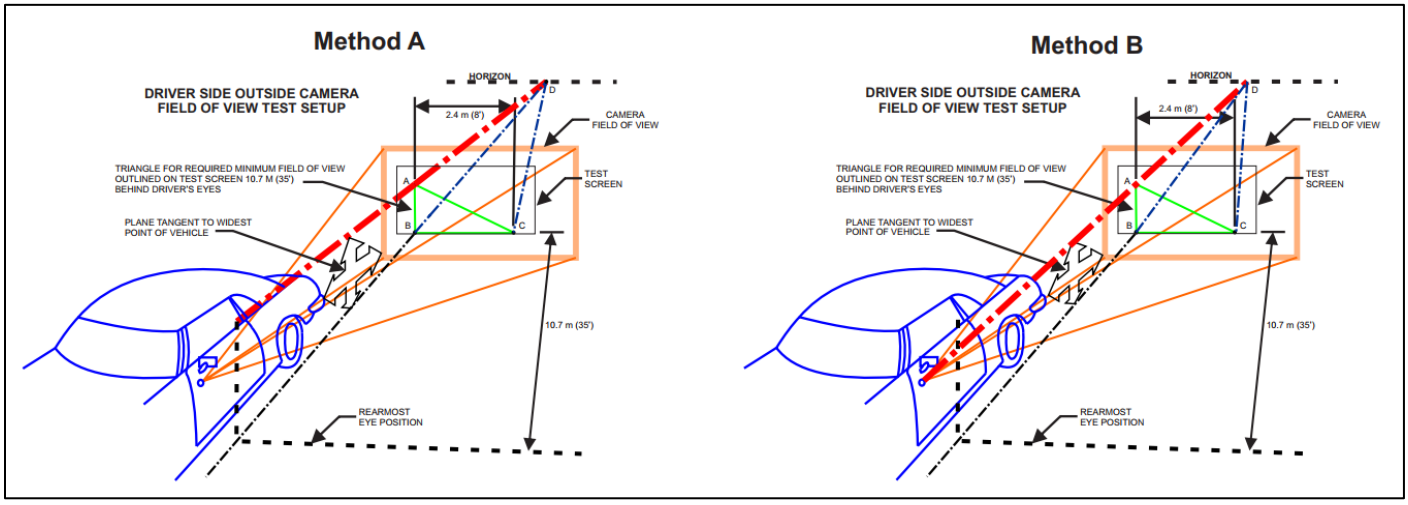


Figure 3 - Comparison of Method A and Method B physical tests

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7. Install a reference camera positioning fixture in the vehicle. The reference camera shall be located using the fixture such that the reference camera lens is in the reference eye position. The reference camera positioning fixture shall be designed such that the reference camera can be rotated about the vertical axis.

8. If the monitor position is adjustable, then set the monitor position to the nominal design position.

9. If the camera displayed region of interest is adjustable, adjust the region of interest to the default setting.

10. Photograph the image of the monitor.

11. Utilizing the photograph of the rearview image, verify and record that all the edges outside rearview CMS - driver's side field of view are visible.

4.1.1.2 Outside Rearview CMS - Passenger's Side Field of View

4.1.1.2.1 Outside Rearview CMS - Passenger's Side Field of View Requirement

The passenger's outside rearview CMS shall provide the driver with a view of a level road surface extending to the horizon from a line, perpendicular to a longitudinal plane tangent to the passenger's side of the vehicle at the widest point, extending 2.4 m out from the tangent plane 10.7 m behind the driver's eyes, with the seat in the rearmost position, when the vehicle is occupied by the driver and four passengers or the designated occupant capacity. The field of view may be partially obscured by rear body or fender contours.

The location of the driver's eye reference points shall be the SAE J941 for CAD-based verifications and the FMVSS 111 RVC for physical test verifications.

NOTE 1: The field of view of the passenger's side outside rearview CMS should cover at least the minimum field of view for a conventional passenger's side outside mirror of unit magnification.

NOTE 2: The camera view and its location will be a trade-off between camera height and depth perception.

NOTE 3: To avoid an unnatural driving perspective, a low camera mounting location should be avoided; see Appendix A.

4.1.1.2.2 Outside Rearview CMS - Passenger's Side Field of View Verification Test - CAD Evaluation

Method A

The CMS field of view can be evaluated through CAD by creating a triangular region based on the eye-point projection. The height of the triangular region is determined by choosing a horizon point (e.g., 150 m) and projecting to the plane at 10.7 m behind the driver's eyes along the sight line from the vehicle's eye point projected to the longitudinal plane tangent to the passenger's side of the vehicle at the widest point. The triangular region can then be evaluated from the camera's entrance pupil as defined in CAD according to the designed position and viewing angles.

Method B

Alternatively, the CMS field of view can be evaluated through CAD by creating a triangular region based on the height of the CMS camera entrance pupil when attached to the vehicle. The height of the triangular region is determined by choosing a horizon point (e.g., 150 m) and projecting to the plane at 10.7 m behind the driver's eyes along the sight line from the vehicle's CMS camera entrance pupil projected to the longitudinal plane tangent to the passenger's side of the vehicle at the widest point. The triangular region can then be evaluated from the camera's entrance pupil as defined in CAD according to the designed position and viewing angles.

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CAD Evaluation Procedure

1. Generate CAD-based targets depicting the outside rearview CMS - passenger's side field of view.

2. Generate CAD representations of the outside rearview CMS - passenger's side cameras' field of view.

3. Verify and record the result, showing that the views captured by the camera design are capable of fully displaying the outside rearview CMS - passenger's side field of view.

4.1.1.2.3 Outside Rearview CMS - Passenger's Side Field of View Verification Test - Physical Test

Physical Test Procedure

The outside rearview CMS - passenger's side field of view can be evaluated through a physical test according to the following procedure:

1. Maneuver the vehicle onto a predetermined location on the level floor of the test laboratory.

2. Establish a vertical longitudinal plane tangent to the widest point of the test vehicle on the passenger's side (parallel to the centerline of the vehicle) and locate its intersection with the floor.

3. Measure 10.7 m (35 feet) to rear of the driver's eye location and set up a field-of-view test screen perpendicular to the tangent plane.

4. Load the vehicle to simulate the driver and four passengers (unless capacity is less) with ballast of 68 kg (150 pounds) per occupant.

5. Block and secure the vehicle in place to eliminate vertical or horizontal motion during the test.

6. Mark the edges of the outside rearview CMS - passenger's side field of view using tape, paint, or any other acceptable means; see Figure 1 for Method A and Figure 2 for Method B.

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Method A

For Method A, calculate the height of A assuming a horizon of not less than 150 m (e.g., A = eye-point height x [150 - 10.7] / 150); see Figure 4.

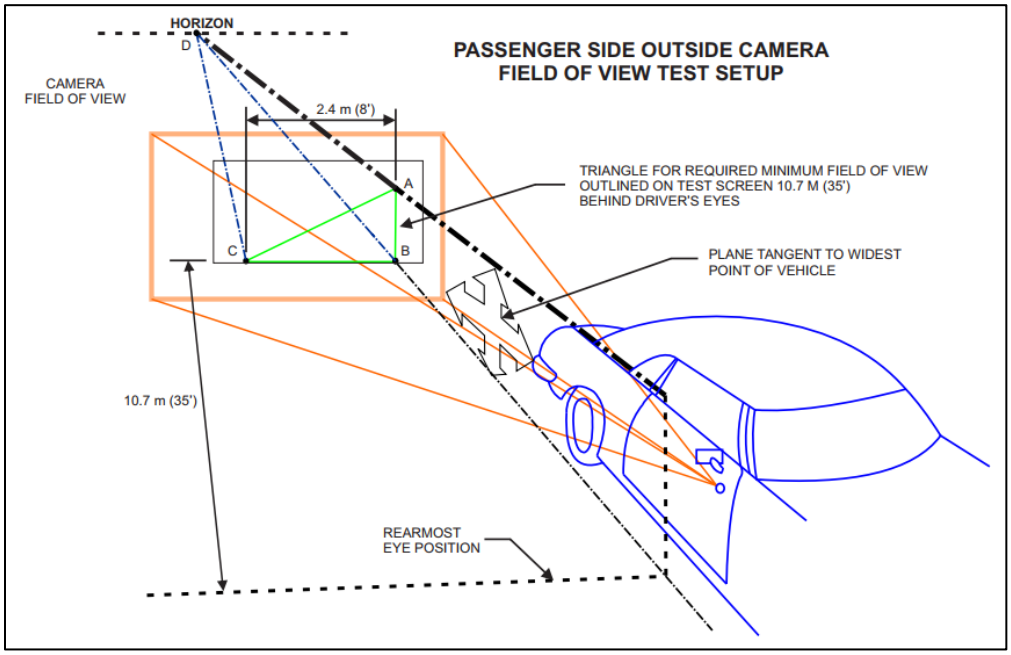


Figure 4 - Verification test - Method A, physical test

Method B

For Method B, calculate the height of A assuming a horizon of not less than 150 m (e.g., A = camera entrance pupil height x [150 - 10.7 + X_{cam}] / 150), where X_{cam} is the camera position in X relative to the eye-point position in X and is positive if the camera is positioned forward of the eye-point in the longitudinal direction; see Figure 5.

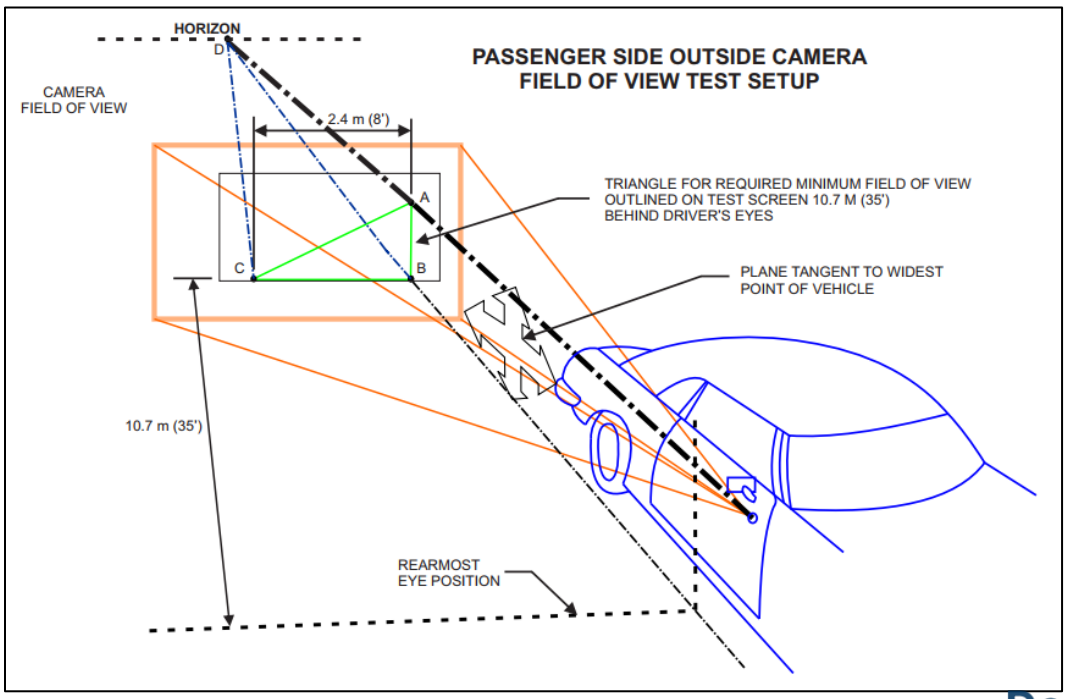


Figure 5 - Verification test - Method B, physical test

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A comparison of Method A and Method B physical tests is shown in Figure 6. Note the difference in the projection line passing through A to D. See Appendix A.

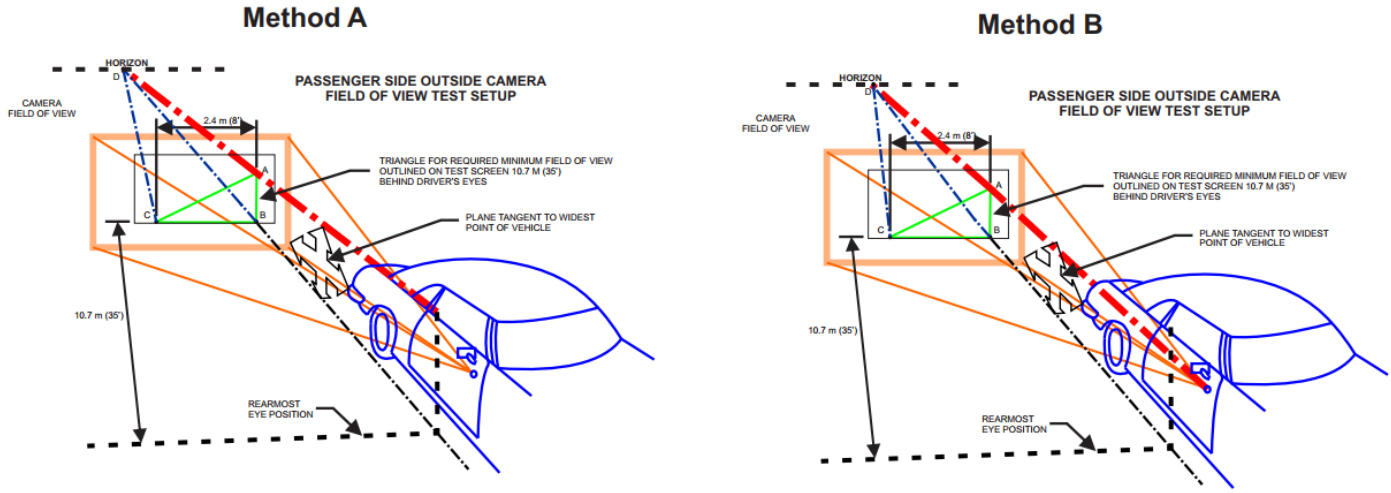


Figure 6 - Comparison of Method A and Method B physical tests

7. Install a reference camera positioning fixture in the vehicle. The reference camera shall be located using the fixture such that the reference camera lens is in the reference eye position. The reference camera positioning fixture shall be designed such that the reference camera can be rotated about the vertical axis.

8. If the monitor position is adjustable, then set the monitor position to the nominal design position.

9. If the camera displayed region of interest is adjustable, adjust the region of interest to the default setting.

10. Photograph the image of the monitor.

11. Utilizing the photograph of the rearview image, verify and record that all the edges outside rearview CMS - passenger's side field of view are visible.

4.1.1.3 Inside Rearview CMS Field of View

4.1.1.3.1 Inside Rearview CMS Field of View Requirement

The inside rearview CMS shall provide the driver with a field of view with an included horizontal angle measured from the projected eye point of at least 20 degrees, and a sufficient vertical angle to provide a view of a level road surface extending to the horizon beginning at a point not greater than 61 m to the rear of the vehicle, when the vehicle is occupied by the driver and four passengers or the designated occupant capacity, if less, based on an average occupant weight of 68 kg.

The location of the driver's eye reference points shall be the SAE J941 for CAD-based verifications and the FMVSS 111 RVC for physical test verifications.

The location of the projected eye point shall be as defined in Appendix B.

NOTE: The field of view of the inside rearview CMS should cover at least the minimum field of view for a conventional inside rearview mirror.

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4.1.1.3.2 Inside Rearview CMS Field of View Verification Test - CAD Evaluation

The inside rearview CMS field of view can be evaluated through CAD by creating a region with an included horizontal angle of 20 degrees from the projected eye point and sufficient vertical angle to provide a view of a level road surface extending to the horizon beginning at a point not greater than 61 m to the rear of the vehicle. The region can then be evaluated from the camera's entrance pupil as defined in CAD according to the designed position and viewing angles.

CAD Evaluation Procedure

1. Generate CAD-based targets depicting the inside rearview CMS field of view.
2. Generate CAD representations of the inside rearview CMS cameras' field of view.
3. Verify and record the result, showing that the views captured by the camera design are capable of fully displaying the inside rearview CMS field of view.

4.1.1.3.3 Inside Rearview CMS Field of View Verification Test - Physical Test

The inside rearview CMS field of view can be evaluated through a physical test according to the following procedure:

Physical Test Procedure

1. Maneuver the vehicle onto a predetermined location on the level floor of the test laboratory.
2. Establish a vertical longitudinal plane tangent to the widest point of the test vehicle on the driver's side (parallel to the centerline of the vehicle) and locate its intersection with the floor.
3. Measure 10.7 m (35 feet) to rear of the driver's eye location and set up a field-of-view test screen perpendicular to the tangent plane.
4. Load the vehicle to simulate the driver and four passengers (unless capacity is less) with ballast of 68 kg (150 pounds) per occupant.
5. Block and secure the vehicle in place to eliminate vertical or horizontal motion during the test.
6. If the monitor position is adjustable, set the monitor to the nominal design position.
7. If the camera displayed region of interest is adjustable, adjust the region of interest to the default setting.
8. Install a reference camera positioning fixture in the vehicle. The reference camera shall be located using the fixture such that the reference camera lens is in the reference eye position. The reference camera positioning fixture shall be designed such that the reference camera can be rotated about the vertical axis.
9. Measure the vertical height to the projected eye point. This is $Z2_{CMS}$, as shown in Figure 7.
10. While observing the inside rearview CMS monitor, have an assistant place a marker on the field of view screen at the vehicle centerline at a location where the target appears at the lower edge of the monitor. This is $Z1_{CMS}$, as shown in Figure 7. This point will be used to calculate the distance at which the level road surface would be first visible.
11. While observing the inside rearview CMS monitor, have an assistant place a marker on the field of view screen at the extreme left and right sides of the monitor view. These are YL_{CMS} and YR_{CMS}, as shown in Figure 7. These points will be used to calculate the included horizontal angle.
12. Photograph the image of the monitor.

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13. Calculate the distance $X2_{CMS}$ according to Figure 7 and the following:

$$X2_{CMS} = [(Z2_{CMS} * X1) + (Z1_{CMS} * C)]/(Z2_{CMS} - Z1_{CMS})$$

where:

E_{CMS} = standard projection distance

A = distance from rear of vehicle to projected eye point location

C = distance from camera position to rear of vehicle

X1 = distance from rear of vehicle to field of view grid

$X2_{CMS}$ = calculated distance where a CMS would first display a level road surface; must be less than or equal to 61 m minus the horizontal difference of the camera position relative to the projected eye point of a mirror, i.e., $X2_{CMS} \leq$ 61 m - (A - C), in meters.

$Z1_{CMS}$ = vertical distance to lowest point of field of view at distance X1

$Z2_{CMS}$ = vertical height to the eye point

14. Calculate the width on the field of view test screen according to Figure 7 and the following:

$$Y_{CMS} = YL_{CMS} + YR_{CMS}$$

where:

YL_{CMS} = maximum distance to driver's left of center line that is viewed on the grid

YR_{CMS} = maximum distance to driver's right of center line that is viewed on the grid

Y_{CMS} = calculated width on the field-of-view test screen; must be greater than or equal to:

$$2 * \tan(20 \text{ degrees}/2) * (61\text{m} + A) * [(X1 + C)/(61\text{m} + C)], \text{ in meters}$$

A = distance from rear of vehicle to projected eye point location

C = distance from camera position to rear of vehicle

X1 = distance from rear of vehicle to field of view grid

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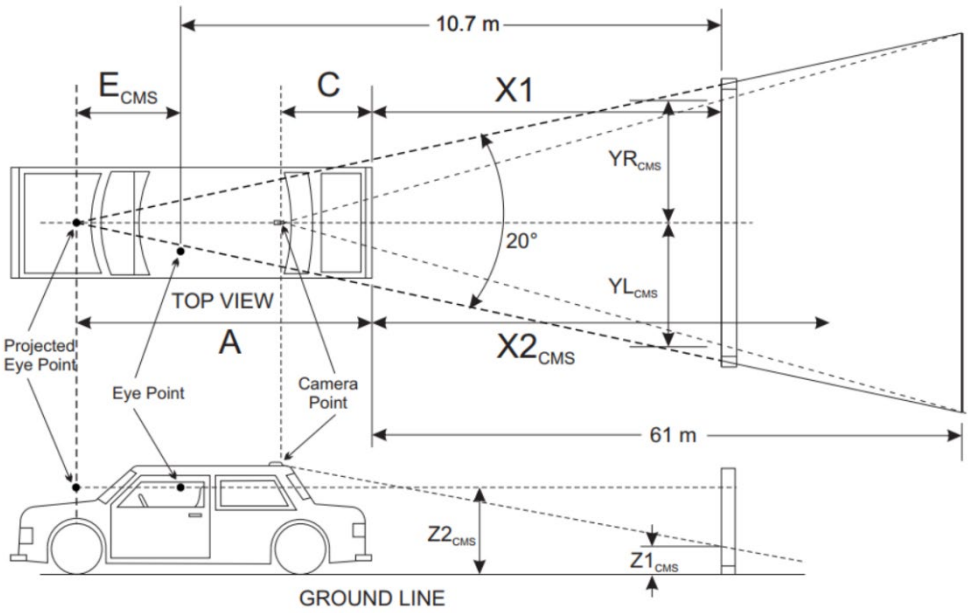


Figure 7 - Verification test - physical test

4.1.2 Field of View - Heavy Trucks

The CMS shall be capable of displaying two separate views, main and wide-angle views at the same time, covering different regions on the ground in normal operating mode. The configuration of the ground zone views on the monitor could be separate or combined into a single view. Different fields of view(s) may be displayed automatically or manually to assist in maneuvering the vehicle in place of the main and wide-angle views.

4.1.2.1 Main View

4.1.2.1.1 Requirement

The driver's outside rearview CMS shall provide the driver a view of a level road surface such that the driver can see at least a 5-m wide, flat, horizontal portion of the road, which is bounded by a plane which is parallel to the median longitudinal vertical plane and passing through the outermost point of the vehicle on the driver's and passenger's sides of the vehicle and extends from 30 m behind the driver's ocular points to the horizon.

In addition, the road shall be visible to the driver over a width of 1 m, which is bounded by a plane parallel to the median longitudinal vertical plane and passing through the outermost point of the vehicle starting from a point 4 m behind the vertical plane passing through the driver's ocular points (see Figure 8).

The location of the driver's eye reference point shall be a point 635 mm above the vehicle manufacturer's seating reference point (SRP).

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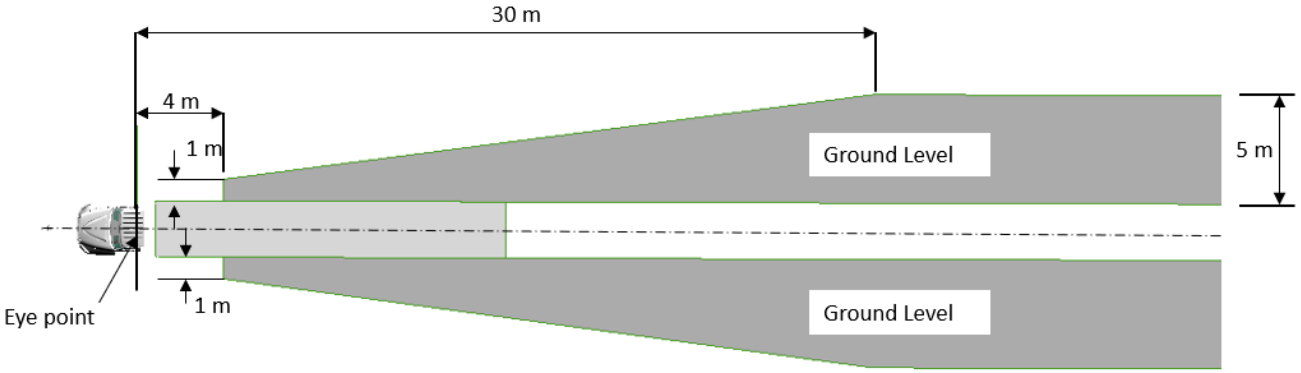


Figure 8 - Heavy truck field of view - main view

4.1.2.2 Wide-Angle View

4.1.2.2.1 Requirement

The driver's outside rearview CMS shall provide the driver a view of a level road surface such that the driver can see at least a 15-m wide, flat, horizontal portion of the road, which is bounded by a plane parallel to the median longitudinal vertical plane of the vehicle and passing through the outermost point of the vehicle on the driver's and passenger's sides and which extends from at least 10 to 25 m behind the driver's ocular points.

In addition, the road shall be visible to the driver over a width of 4.5 m, which is bounded by a plane parallel to the median longitudinal vertical plane and passing through the outermost point of the vehicle starting from a point 1.5 m behind the vertical plane passing through the driver's ocular points (see Figure 9).

The location of the driver's eye reference point shall be a point 635 mm above the vehicle manufacturer's seating reference point (SRP).

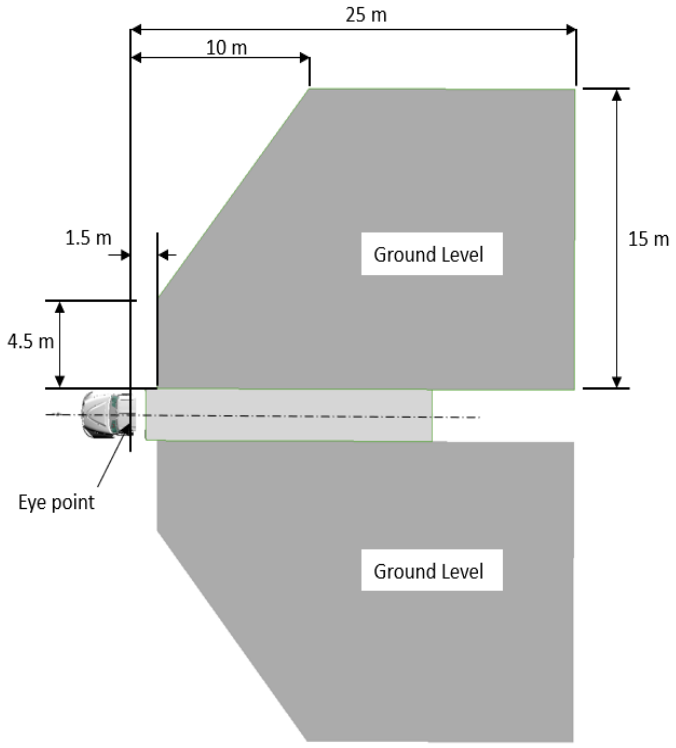


Figure 9 - Heavy truck field of view - wide-angle view

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4.1.2.3 Verification Test - CAD Evaluation

The heavy truck CMS field of view can be evaluated through CAD by creating CAD representations of the CMS cameras' fields of view (FOV).

CAD Evaluation Procedure

1. Establish a ground plane for the vehicle in the unladen condition.

2. Generate CAD zones on the ground plane depicting the main and wide-angle views shown in Figures 8 and 9.

3. For the main view, create a geometric representation of the horizon. The horizon can be modeled by a linear object located at the height of the camera's entrance pupil and positioned greater than 30 m rearward of the driver's eye reference point.

4. Generate CAD representations of the driver and passenger-side CMS cameras' field of views. The simulated monitor output should also indicate the areas covered by overlays (if available).

5. Verify and record the result, showing that the views captured by the camera design are capable of fully displaying the main and wide-angle views with the fields of view of the CMS cameras. Verify that the overlays do not obstruct the minimum FOV more than the percentage specified in 4.1.9.6.

4.1.2.4 Verification Test - Physical Test

Evaluation of the field of view on the CMS monitor could be conducted using a photographic verification method.

Physical Test Procedure

1. Maneuver the unladen test vehicle onto a predetermined location on a level floor.

2. Block and secure the vehicle in place to eliminate vertical or horizontal motion during the test.

3. Mark the edges of the main and wide-angle view zones on the ground using tape, paint, or any other acceptable means. For the main view zones, mark the edge of the main view zone such that that rear edge is more than 30 m rearward of the eye reference point (as shown in Figure 8).

4. Attach a transparent sheet to each of the monitors. Trace the contours of the active area of the displays onto the transparent sheet. Additionally, trace the contours of the main view FOV bounding rectangle. Repeat with procedure with new transparent sheets to plot the wide-angle FOV bounding rectangles. Step 4 is not required for the FOV test; this is a supporting step for the resolution test specified in 4.1.6.

5. To represent the horizon, install rectangular or cylindrical objects to represent the horizon. The horizon objects should be positioned 30 m or more rearward of the reference eye point. The lower edge of the geometric objects should coincide with the height of the cameras' respective entrance pupil. The horizon objects should be perpendicular to the longitudinal vehicle axis, such that one end coincides with the plane tangential to the vehicle width. An object reference for the horizon is not required if this test is conducted outdoors where an image of the horizon can be captured.

6. Install a camera positioning fixture in the truck cab. The camera shall be located using the fixture such that the camera lens is in the reference eye position. The camera positioning fixture shall be designed such that the camera can be rotated about the vertical axis.

7. If the monitor positions are adjustable, then set the monitor positions to the nominal design positions.

8. Adjust the camera position such that the camera lens is directed at the center of the driver-side monitor.

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9. Photograph the image of the monitor.

10. Utilizing the photograph of the rearview image, verify and record that all the edges of the driver-side main and wide-angle zones are visible. This physical setup will also be used for the resolution test. See 4.1.6 for additional information on how to use this test setup for the resolution test.

11. Repeat steps 8 to 10 with the passenger-side monitor.

4.1.3 Image Size - Passenger Cars

4.1.3.1 Outside Rearview CMS - Driver's Side Image Size

4.1.3.1.1 Outside Rearview CMS - Driver's Side Image Size Requirement

The outside rearview CMS - driver's side shall present to the driver the test object with a calculated visual angle subtended by the horizontal width of not less than 61 minutes of arc.

NOTE 1: The image size shown in the CMS should be as expected by the driver; see Appendix C.

NOTE 2: The mounting location of the CMS camera may influence the apparent size of the test object.

The test object shall be 305 mm (12 inches) wide and 152 mm (6 inches) high and be positioned at the uppermost position within the field of view target. An example is given in Figure 10 for a typical sedan and in Figure 11 for a typical pickup truck.

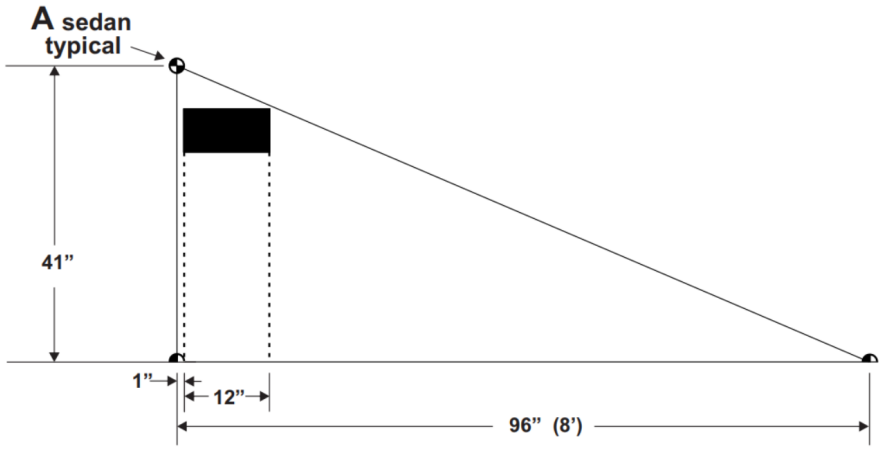


Figure 10 - Image size test object with the field of view target for a typical sedan

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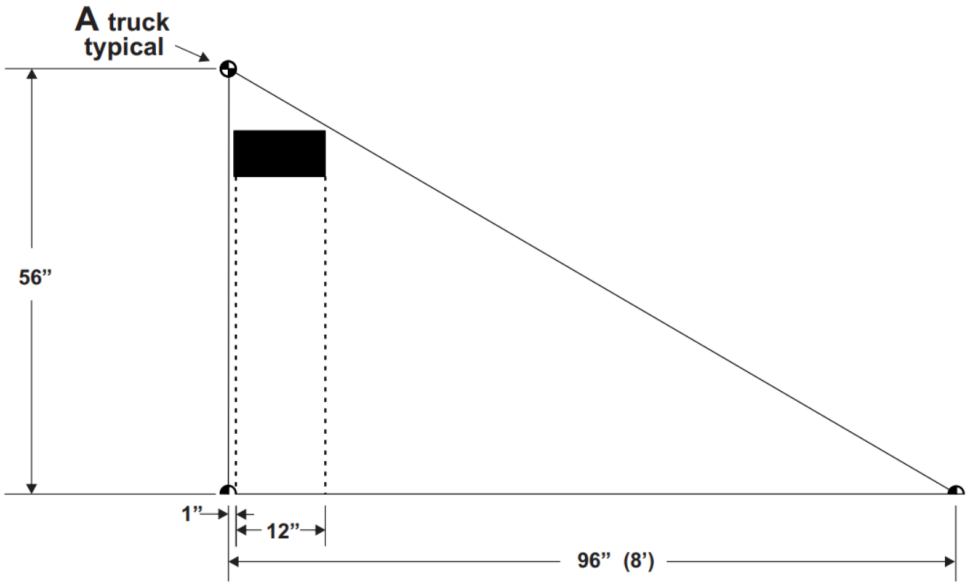


Figure 11 - Image size test object with the field of view target for a typical pickup truck

4.1.3.1.2 Outside Rearview CMS - Driver’s Side Image Size Verification Test - CAD Evaluation

The outside rearview CMS - driver’s side image size can be evaluated through CAD by creating a triangular field of view region (see 4.1.1.1) and placing the test object within the field of view. The image size can then be evaluated from the camera’s entrance pupil as defined in CAD according to the designed position and viewing angles.

CAD Evaluation Procedure

1. Generate a CAD-based target depicting the outside rearview CMS - driver’s side field of view.
2. Generate a CAD-based test object within the field of view triangle (see 4.1.1.1).
3. Generate CAD representations of the outside rearview CMS - driver’s side cameras’ field of view.
4. Verify and record visual angle subtended by the horizontal width of the test object.

4.1.3.1.3 Outside Rearview CMS - Driver’s Side Size Verification Test - Physical Test

The outside rearview CMS - driver’s side image size can be evaluated through a physical test by creating a triangular field of view region (see 4.1.1.1) and placing the test object within the field of view. The image size can then be evaluated according to the following procedure.

Physical Test Procedure

The outside rearview CMS - driver’s side image size can be evaluated through a physical test according to the following procedure:

1. Maneuver the vehicle onto a predetermined location on the level floor of the test laboratory.
2. Establish a vertical longitudinal plane tangent to the widest point of the test vehicle on the driver’s side (parallel to the centerline of the vehicle) and locate its intersection with the floor.
3. Measure 10.7 m (35 feet) to rear of the driver’s eye location and set up a field-of-view test screen perpendicular to the tangent plane.
4. Load the vehicle to simulate the driver and four passengers (unless capacity is less) with ballast of 68 kg (150 pounds) per occupant.

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5. Block and secure the vehicle in place to eliminate vertical or horizontal motion during the test.

6. Mark the edges of the outside rearview CMS - driver's side field of view using tape, paint, or any other acceptable means; see 4.1.1.1.

7. Place the test object within the field of view triangle according to 4.1.1.1. The test object can be a free-standing cylinder or a placard affixed to the field of view screen; see Figure 12.

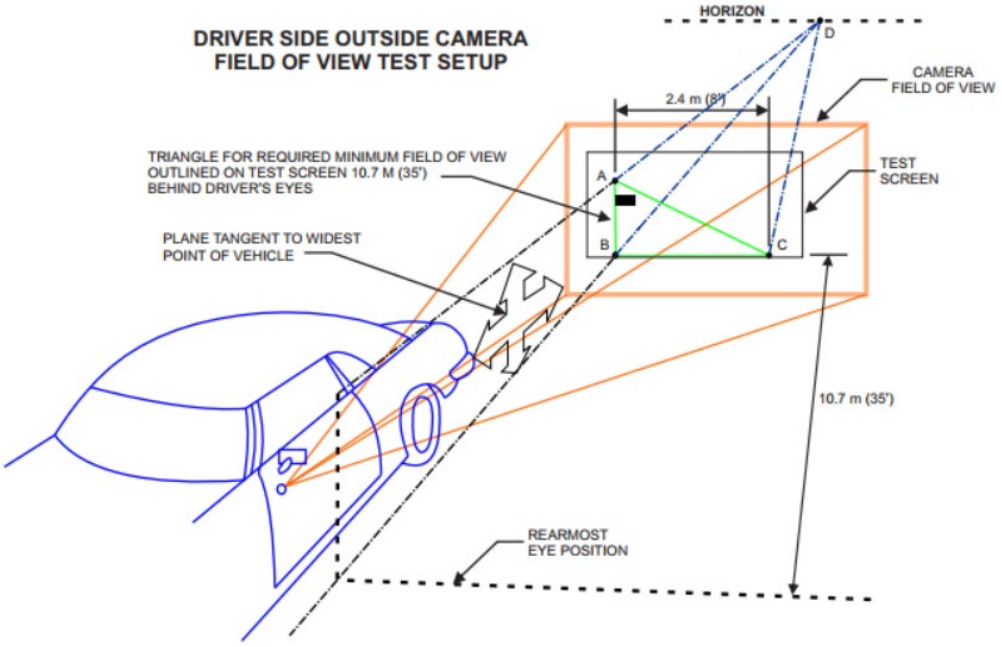


Figure 12 - Image size test object with the field of view target - driver's side

8. Install a reference camera positioning fixture in the vehicle. The reference camera shall be located using the fixture such that the reference camera lens is in the reference eye position. The reference camera positioning fixture shall be designed such that the reference camera can be rotated about the vertical axis.

9. If the monitor position is adjustable, then set the monitor position to the nominal design position.

10. If the camera displayed region of interest is adjustable, adjust the region of interest to the default setting.

11. Place a 50-mm calibration scale within the monitor viewing area. Photograph the image of the monitor.

12. Utilizing the photograph of the rearview image and the 50-mm calibration scale, verify and record the visual angle subtended by the horizontal width of the test object.

4.1.3.2 Outside Rearview CMS - Passenger's Side Image Size

4.1.3.2.1 Outside Rearview CMS - Passenger's Side Image Size Requirement

The outside rearview CMS - passenger's side shall present to the driver the test object with a calculated visual angle subtended by the horizontal width of not less than 27 minutes of arc.

NOTE 1: The image size shown in the CMS should be as expected by the driver; see Appendix C.

NOTE 2: The mounting location of the CMS camera may influence the apparent size of the test object.

The test object shall be 305 mm (12 inches) wide and 152 mm (6 inches) high and be positioned at the uppermost position within the field of view target. An example is given in Figure 13 for a typical sedan and in Figure 14 for a typical pickup truck.

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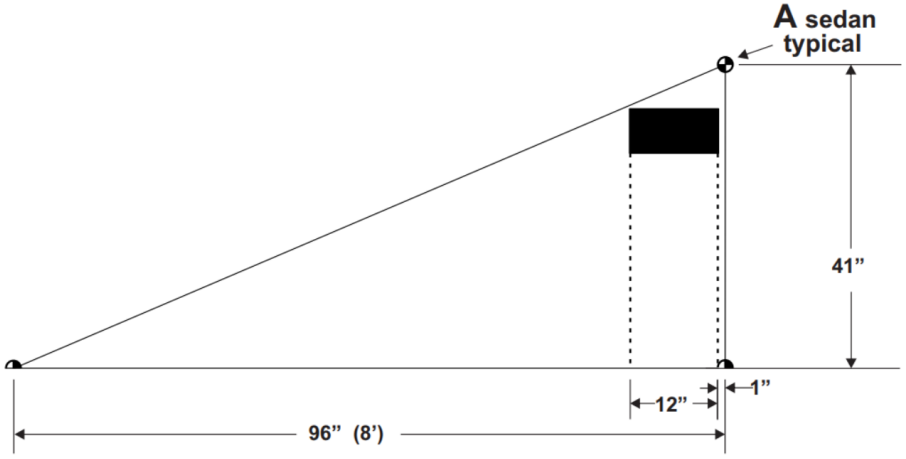


Figure 13 - Image size test object with the field of view target for a typical sedan

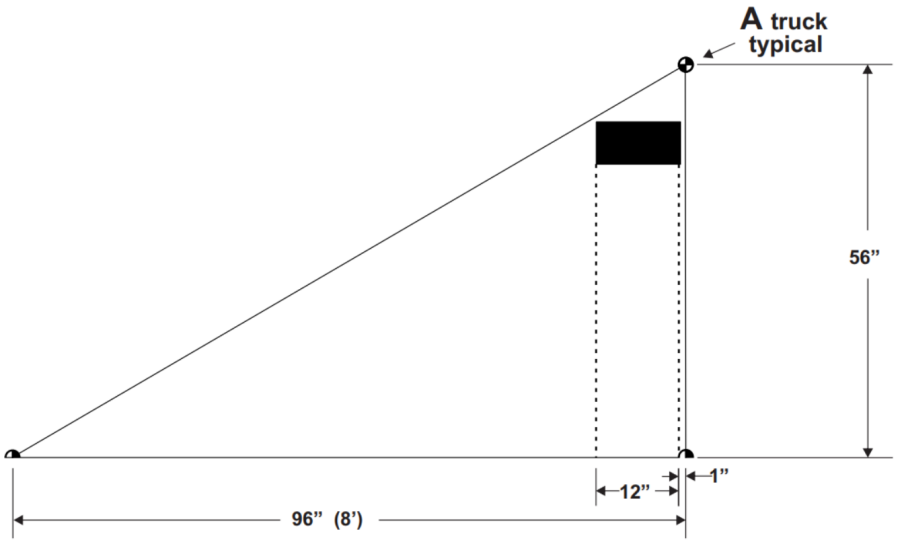


Figure 14 - Image size test object with the field of view target for a typical pickup truck

4.1.3.2.2 Outside Rearview CMS - Passenger’s Side Image Size Verification Test - CAD Evaluation

The outside rearview CMS - passenger’s side image size can be evaluated through CAD by creating a triangular field of view region (see 4.1.1.2) and placing the test object within the field of view. The image size can then be evaluated from the camera’s entrance pupil as defined in CAD according to the designed position and viewing angles.

CAD Evaluation Procedure

1. Generate a CAD-based target depicting the outside rearview CMS - passenger’s side field of view.
2. Generate a CAD-based test object within the field of view triangle (see 4.1.1.2).
3. Generate CAD representations of the outside rearview CMS - passenger’s side cameras’ field of view.
4. Verify and record visual angle subtended by the horizontal width of the test object.

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4.1.3.2.3 Outside Rearview CMS - Passenger's Side Image Size Verification Test - Physical Test

The outside rearview CMS - passenger's side image size can be evaluated through a physical test by creating a triangular field of view region (see 4.1.1.2) and placing the test object within the field of view. The image size can then be evaluated according to the following procedure.

Physical Test Procedure

The outside rearview CMS - passenger's side image size can be evaluated through a physical test according to the following procedure:

1. Maneuver the vehicle onto a predetermined location on the level floor of the test laboratory.
2. Establish a vertical longitudinal plane tangent to the widest point of the test vehicle on the passenger's side (parallel to the centerline of the vehicle) and locate its intersection with the floor.
3. Measure 10.7 m (35 feet) to rear of the driver's eye location and set up a field-of-view test screen perpendicular to the tangent plane.
4. Load the vehicle to simulate the driver and four passengers (unless capacity is less) with ballast of 68 kg (150 pounds) per occupant.
5. Block and secure the vehicle in place to eliminate vertical or horizontal motion during the test.
6. Mark the edges of the outside rearview CMS - passenger's side field of view using tape, paint, or any other acceptable means; see 4.1.1.2.
7. Place the test object within the field of view triangle according to 4.1.1.2. The test object can be a free-standing cylinder or a placard affixed to the field of view screen; see Figure 15.

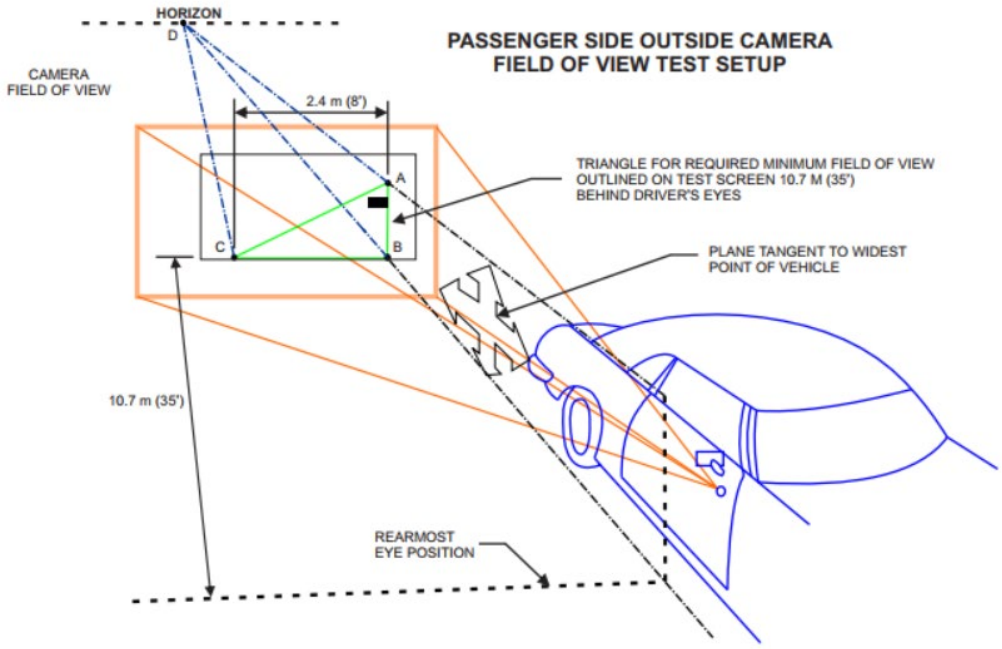


Figure 15 - Image size test object with the field of view target - passenger's side

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8. Install a reference camera positioning fixture in the vehicle. The reference camera shall be located using the fixture such that the reference camera lens is in the reference eye position. The reference camera positioning fixture shall be designed such that the reference camera can be rotated about the vertical axis.

9. If the monitor position is adjustable, then set the monitor position to the nominal design position.

10. If the camera displayed region of interest is adjustable, adjust the region of interest to the default setting.

11. Place a 50-mm calibration scale within the monitor viewing area. Photograph the image of the monitor.

12. Utilizing the photograph of the rearview image and the 50-mm calibration scale, verify and record visual angle subtended by the horizontal width of the test object.

4.1.3.3 Inside Rearview CMS Image Size

4.1.3.3.1 Inside Rearview CMS Size Image Requirement

The inside rearview CMS shall present to the driver the test object with a calculated visual angle subtended by the horizontal width of not less than 78 minutes of arc.

NOTE 1: The image size shown in the CMS should be as expected by the driver; see Appendix C.

NOTE 2: The mounting location of the CMS camera may influence the apparent size of the test object.

The test object shall be 305 mm (12 inches) wide and 152 mm (6 inches) high and be positioned at the center position within the field of view target. An example is given in Figure 16.

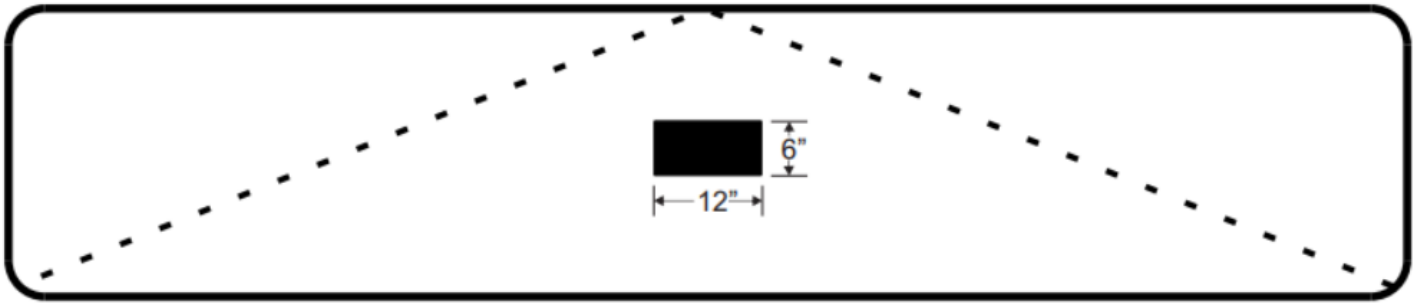


Figure 16 - Image size test object with the field of view target

NOTE: The test object is placed at the center of the target so that it can be evaluated in CAD using either the divergent projection (rectangular target in solid line) or the convergent target (triangular target in dashed line), depending on the method used.

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