

Development of a Performance Specification for Camera/Video Imaging Systems on Heavy Vehicles

Final Report: Specifications



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METRIC CONVERSION CHART

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

TABLE OF CONTENTS

TECHNICAL REPORT DOCUMENT PAGE	iii
METRIC CONVERSION CHART	v
LIST OF FIGURES	viii
LIST OF TABLES	ix
ABBREVIATIONS AND NOMENCLATURE.....	xi
ABSTRACT.....	xiii
ACKNOWLEDGEMENTS AND DISCLAIMER NOTICE.....	xv
REQUIREMENTS FOR CAMERA/VIDEO IMAGING SYSTEMS FOR HEAVY VEHICLES	1
I. INTRODUCTION.....	1
Requirements for Surrogates.....	1
Requirements for Enhancements	2
General Camera Requirements	2
General System Requirements.....	3
C/VIS Concepts	4
II. INDIVIDUAL CONCEPT SPECIFICATIONS	7
II A. SURROGATES.....	13
Concept Name: Left and Right Flat (West Coast) Mirror Surrogates	13
Concept Name: Convex Left and Right-Side Mirror Surrogates.....	22
II B. ENHANCEMENTS.....	25
Concept Name: Front Blind-Spot Enhancement.....	25
Concept Name: Right Side Wide-Angle Blind-Spot Enhancement	26
Concept Name: Left Side Blind-Spot Enhancement	27
Concept Name: Tractor Rear Backing/Bobtailing Enhancement	28
Concept Name: Left and Right Merge/Re-merge Enhancements.....	29
Concept Name: Trailer Rear-View Enhancement	30
Concept Name: Trailer Rear Look-Down Enhancement.....	31
Concept Name: Wide-Angle Trailer Rear Multipurpose Look-Down Enhancement	32
Concept Name: Trailer Rear Multi-Camera Enhancement.....	34
III. ADDITIONAL COMMON DETAILED SPECIFICATIONS.....	35
System Operating Temperature Range; Exposure Temperature Range	35
Exterior Illumination Operating Range	35
Cab Interior Illumination Operating Range	35
Monitor Luminance/Contrast Adjustment	36
Monitor Luminance Fluctuation	36
System Minimum Image Resolution	36
System Refresh Rate	36
System Maximum Image Delay.....	36
System Persistence.....	36
System Reliability	37
Vibration and Shock Immunity.....	37
Response to Activation	37
Image Aspect Ratio.....	37
REFERENCE.....	39

LIST OF FIGURES

Figure 1. First group of camera locations.	8
Figure 2. Second group of camera locations.....	9
Figure 3. Monitor locations at the A-pillars.....	10
Figure 4. Other monitor locations.....	10
Figure 5. Comparison of theoretically optimum and fender-mount camera positions.	16
Figure 6. Hypothetical equivalent video system for a mirror.	17
Figure 7. Equivalent monitor locations for a mirror surrogate video system.	18
Figure 8. FOV for ambinocular vision.....	19

LIST OF TABLES

Table 1. Monitor image sizes used in the specifications.	11
Table 2. Monitor screen width as a function of distance from the driver's eyes.....	20

ABBREVIATIONS AND NOMENCLATURE

- AGC:** automatic gain control; electronic system for automatically adjusting the brightness or level of a video signal (in this document)
- ambinocular view:** a view that is seen by either eye or both eyes; the total view
- A-pillar:** the structure at the left or right side of the windshield
- auto-iris function:** a system whereby a camera's electro-mechanical lens aperture is automatically adapted to the scene lighting available
- camera field of view; camera horizontal field of view:** in this document, horizontal field of view in degrees of a camera in its normal or upright position, regardless of how the camera is aimed in the application
- C/VIS:** camera/video imaging system; a video system composed of a camera, monitor, and all supporting subsystems including lens, interconnections, and power
- deg; °:** angular unit of measurement, degree
- enhancement:** a camera/video imaging system that replaces a nonessential mirror, supplements a nonessential mirror, or provides an additional view around a heavy vehicle
- FMCSA:** Federal Motor Carrier Safety Administration
- FOV:** angular field of view
- h:** hour
- IP:** vehicle instrument panel
- interlace:** in video systems, a method of reducing flicker by sequentially generating every other line of a reproduced scene and then sequentially generating the lines in between
- km/h:** kilometers per hour
- mph:** miles per hour
- ms:** millisecond
- NHTSA:** National Highway Traffic Safety Administration
- on-road; over-the-road:** a term implying operating at highway speeds
- reversed scan:** in this document, a mirror image presentation of a video scene; that is, left to right (horizontal) reversal of the image
- s:** second
- standard scan:** in this document, a video scene presentation in which the scene is not reversed. Objects on the left in the actual scene appear on the left in the video scene; similarly, objects on the right in the actual scene appear on the right in the video scene.
- surrogate:** a camera/video imaging system that replaces either the flat or the convex (essential) mirror on either the driver or the passenger side of the tractor
- VTTI:** Virginia Tech Transportation Institute
- west coast mirror:** a flat, elongated mirror used on the side of a heavy vehicle; usually, this mirror is approximately 6 in (15.2 cm) wide by approximately 14 in (35.6 cm) long.
- yard/urban:** a term used to describe backing and sharp-turn maneuvering

ABSTRACT

This document provides revised final performance specifications for camera/video imaging systems (C/VISs) used in heavy vehicles. The specifications are based on a combination of analyses including driver needs and human factors, current and future video technology, systems analyses, focus groups, preliminary tests, and formal on-road tests. In these specifications, C/VISs are divided into two categories: surrogates, which take the place of the essential side mirrors, and enhancements, which are all other applications. The specifications are written in three parts: an introductory section defining terms and stating general requirements, a section providing detailed specifications for two surrogate configuration concepts and nine enhancement concepts, and a section providing additional common detailed specifications. The specifications are intended to serve as a culmination of best approaches and practices for development of viable C/VISs. It is expected that if the specifications are followed, they will result in feasible and reasonably uniform implementation, thereby making the heavy vehicle driver's task more efficient. For background information and research justification of the specifications, the reader is referred to the companion final report, *Development of a Performance Specification for Camera/Video Imaging Systems on Heavy Vehicles*, DOT HS 810 960 (Wierwille, Schaudt, Spaulding, Gupta, Fitch, Wiegand, & Hanowski, 2007).

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REQUIREMENTS FOR CAMERA/VIDEO IMAGING SYSTEMS FOR HEAVY VEHICLES

I. INTRODUCTION

A Camera/Video Imaging System is a system composed of a camera and a monitor, as well as other components, in which the monitor provides a real-time or near real-time visual image of the scene captured by the camera. Such systems are capable of providing remote views to the driver and can therefore be used to provide improved visibility; for example, coverage of blind spots. The requirements detailed in this document apply to tractors, tractors with conventional cargo trailers, and conventional cargo-box straight trucks. Greater detail is provided at the beginning of Section II.

C/VISs and video systems in general may be used in the driver's work position only for purposes of improving vehicle and corresponding environmental visibility. They are specifically prohibited from use for entertainment or other frivolous use because of their driver distraction potential.

C/VISs are defined in two classes: Surrogates and Enhancements. A surrogate replaces either the flat mirror or the convex mirror on one side of the vehicle or the other. (Note that vertically-elongated flat mirrors on the sides of vehicles are often referred to as west-coast mirrors). In other words, a surrogate involves substitution of a C/VIS for one of the four essential mirrors. An enhancement is any other use of a C/VIS for obtaining a remote view. An enhancement (1) replaces any mirror or combination of mirrors, other than the four essential mirrors, (2) provides an additional view to the driver, or (3) provides a better view to the driver than is otherwise available from the driver's position.

Requirements for Surrogates

Because a surrogate replaces an essential mirror, the vehicle on which it is installed cannot be safely driven if the surrogate fails. A surrogate, therefore, must have backup capability in the form of an optical mirror that can be temporarily attached to the vehicle. In addition, video requirements must be met so that the surrogate is adequate in terms of the view it provides.

Surrogates for the two flat/west-coast mirrors (one on each side of the vehicle) must meet additional requirements. The monitor images must appear in true size, and the field of view and perspective of the scene must be as close as possible to that provided by the corresponding mirror. These requirements are necessary because drivers judge distances and speeds using these mirrors. Therefore, to the extent that the C/VIS can provide an appropriate image, it must be designed to do so.

Monitors for surrogates must be placed to the sides of the driver, so that the driver may transition easily (in either direction) between vehicles equipped with surrogates and

vehicles equipped with conventional mirrors. Monitors must be placed in such a way that they minimize any additional blind spots in the direct forward and side scenes. Placing these monitors at the A-pillars, with overlap toward the rear, minimizes blind spots while retaining directional location angles similar to those of the mirrors. Note that the mirrors that are being replaced with C/VISs have blind spots. Their removal reduces the area of blind spots, but this area is offset somewhat by the monitors' overlapping of the A-pillars. Because the flat mirror surrogates must provide images in true size, the monitors will ordinarily be larger in width than the A-pillars.

Requirements for Enhancements

An enhancement has less stringent requirements, but should provide a comprehensive view of the desired scene with minimum distortion. The underlying concept is one of providing a faithful and full reproduction of the defined scene, while minimizing any extraneous visual information. Fields of view that are too narrow will not provide the coverage needed for drivers to make fully informed decisions. Also, overly wide FOVs are to be avoided, because they can result in unnecessary image distortion, extraneous information, and size compression of the needed portion of the image.

Monitors for enhancements must not encroach on the direct forward or side scenes of the driver's work position because doing so would create an unnecessary safety tradeoff between increased blind spots and the enhanced visibility afforded by the C/VIS. Monitors should therefore be mounted in positions such as the side headers, the dash, the doors, and top of the dash, but out of the direct FOV. If there are no surrogates, the monitors can be mounted at the A-pillars, but with monitor sizes that do not overlap appreciably. The position and size of the monitor for each application has been selected based primarily on human factors considerations and experimentation.

General Camera Requirements

As has already been mentioned, camera FOVs must be judiciously chosen to provide adequate coverage of the defined scene, but must not be overly wide. In addition, cameras should have all the required characteristics to provide adequate resolution, sensitivity range, and focus range to perform their required functions over the operating environment. As a general rule, surrogate cameras must at least provide views that operate over the same range of characteristics as the corresponding mirror being replaced. However, both surrogate and enhancement cameras should operate over the widest practical range of encountered light levels and other environmental conditions, so that full advantage is taken of visibility that can be attained with C/VISs.

In camera selection particular attention should be paid to immunity from bright sources in the image field. Camera scenes may include headlights, street lights, and, possibly, early morning or late afternoon sunlight. They should suppress bleed-through and blooming and should have rapid recovery from direct glare of any kind.

Cameras should meet all specifications, regardless of the type of camera used. Color should be considered on its technical merits; namely, its potential use for improved detection and identification capabilities. Research shows that drivers strongly prefer color because it helps to identify objects. Monochrome should similarly be considered on its technical merits; namely, its potential use for higher resolution and at night. Experimentation indicates that drivers much prefer color when it can be made available. Color rendition should be accurate because drivers use it as one form of identifier, particularly in regard to other vehicles near their own heavy vehicle.

C/VIS cameras and their mountings must be rugged. Since the environment in which heavy vehicles operate is often severe, care must be taken to ensure that cameras can stand up in such an environment. Cameras should be installed in weatherproof housings with transparent apertures to protect camera lenses. These housings should be weatherproofed with provision made for removal of interior condensation, if needed. Camera housings should be designed to avoid collection of roadway dust, snow, ice, and other debris. This means that appropriate design from an aerodynamic turbulence standpoint should be used. The housing should repel debris instead of collecting it. Transparent apertures should be easy to clean by both the driver and service personnel. Where cameras are out of normal reach, provision should be made for a cleaning device, such as a self-cleaning system or a manual telescoping brush or cleaning pad.

C/VISs must be designed to withstand the vibration that normally occurs in heavy vehicles. There are two aspects to this problem. The first is the design of the camera so that it can withstand the level of vibration that will occur at the location where it is mounted. The second is the design of the mount itself. It must be rugged, but at the same time must isolate the camera to the extent possible. The design problem becomes more severe as the FOV narrows and as the mounting position causes camera vibration. Particular design attention should be given to any camera with a lens FOV of 30° or less. Such cameras are particularly susceptible to angular vibration of the mount because of the magnifying effect of the narrow FOV lens. As an example, consider a camera with a lens having a 10° FOV that is mounted in an environment in which there is 1° of angular vibration. Such a camera will have vibration excursions of 10 percent of the visual field. Therefore, camera mount design is critical for cameras with long focal length (narrow FOV) lenses.

General System Requirements

All C/VISs should operate over anticipated exterior illumination ranges to the extent practical. In addition, monitors should use cab automatic light sensing to adjust the brightness and contrast to the interior level of the cab. The driver's work position should contain a control that allows the driver to adjust the combined brightness and contrast up or down from the nominal setting of the automatic system.

As a general rule, C/VISs should only be active when they are expected to be needed. The reason for this is that video can be distracting to the driver. Some C/VISs, such as the surrogates, would be expected to operate at all times that the vehicle is in use, while others would only operate when requested by the driver. An example of a C/VIS that would only be used at certain times is a tractor rear backing/bobtailing enhancement. Such a system should be *inactive* when there is a trailer attached to a tractor.

Scan and refresh rates should be such that they do not cause noticeable discrete jumping of the image. In addition, flicker should not be noticeable to the driver in either foveal or peripheral vision, and in both daylight and dark conditions.

Noise and power supply interference should be minimized using good design practices. Since the heavy vehicle environment generally involves appreciable levels of spurious electromagnetic waves, particularly those caused by high current electrical transients, care must be taken to ensure that C/VISs are immune from such interference.

C/VIS components located in the cab of the vehicle must be designed to minimize physical hazards to the driver and passenger, should the vehicle become involved in a collision. In addition, C/VIS components should not present a hazard to the driver or passenger under ordinary circumstances, including entering and exiting the vehicle. Exterior components (primarily camera housings) should be designed so that they do not substantially increase the hazard to pedestrians.

For articulated vehicles, where hard interconnection wiring of cameras is used, a connector should be used between the tractor and trailer that carries the signals from the cameras mounted on the trailer. This connector should be such that it disables all C/VISs requiring a trailer-mounted camera when an appropriately instrumented trailer is not available or not connected to the tractor. In general, video screens that are not in use should be blanked (dark) or retracted.

The specifications contained in this document generally cover discrete use of C/VISs; that is, situations in which the number of such systems in any given heavy vehicle is small. If several C/VISs are used in a given vehicle, they must be coordinated using sound human factors design principles and corresponding test and evaluation. Items to be considered in the design should include activation when needed/deactivation when not needed, coordinated use of monitors, and driver control over selection for activation.

C/VIS Concepts

A listing of concepts with corresponding specifications has been developed, based on the research conducted. This listing contains design elements that have been examined experimentally in both preliminary and formal road tests and found to be satisfactory. In general, C/VISs should meet these specifications. If a manufacturer's design does not specifically meet one or more aspects of the specifications, then the manufacturer should be prepared to defend the deviation with scientific justification that would be replicable

by qualified, unbiased analysts. In other words, deviation from specifications is only permitted with good reason and with replicable data.

It should be mentioned that the C/VISs specified in this document are survivors. Several additional candidate C/VISs were examined and found wanting. Consequently, they are not included in this document. The companion research report discusses and describes all candidates, both those that did survive and those that did not.

II. INDIVIDUAL CONCEPT SPECIFICATIONS

The various concepts that have been developed are presented in this section. Research tests have been conducted to ensure that the concepts are viable. The concepts have also been reviewed by typical commercial vehicle drivers for purposes of determining usefulness.

Camera and monitor locations are shown in Figures 1 through 4. In regard to Figures 3 and 4, the monitors are to be angled toward the driver, so the screens are nearly perpendicular to the driver's line of sight. No monitor should have a deviation of more than 20° from being perpendicular to the driver's nominal line of sight. Additional figures are required for surrogates and are called out where needed. Cameras (and their associated lenses) are specified in terms of their horizontal FOV when the camera is used in its normal upright position. If the camera is aimed downward, its horizontal FOV does not change, because that FOV is associated with the camera in its normal upright position. This approach simplifies camera specification.

The concepts apply generally to tractors, tractors with conventional cargo trailers, and conventional cargo-box straight trucks. Some concepts may not apply to specialized heavy vehicles such as fuel/other liquid carriers, flat-bed carriers, vehicles with over-width loads, or vehicles in which the outside edge of the front fender is laterally displaced inward, relative to the trailer or cargo box by more than 1.0 ft (0.305 m). If it is clear that the concept does not apply to a specialized heavy vehicle, then it should not be used. A manufacturer may propose a concept for such a vehicle, which can be submitted to NHTSA for approval as previously explained. While it is possible that some of the concepts may be applied to transit vehicles or school buses, these vehicles have not been considered in this research and the specifications that follow. Therefore, such vehicles should be considered as a separate problem area for C/VISs, and they are not covered in these specifications except by coincidence.

Certain detailed specifications are common to all concepts or to major groups of concepts, such as surrogates or enhancements. These common detailed specifications are presented following the presentation of concepts and their individual specifications.

Monitor sizes are presented in Table 1. These monitor (image) sizes are currently commercially available in flat panel displays. Note specifically that *image* sizes are specified, not overall package sizes. While it is expected that there will be small variations from manufacturer to manufacturer, or as a result of improved technology, the sizes do provide a general indication of appropriate monitor sizes based on research. Therefore, in the specifications that follow, designers should attempt to use monitors of similar sizes or somewhat larger (provided they can be appropriately fitted). In particular, reductions of more than 5 percent should be given especially careful consideration, with documentation of the reasons for making the change.

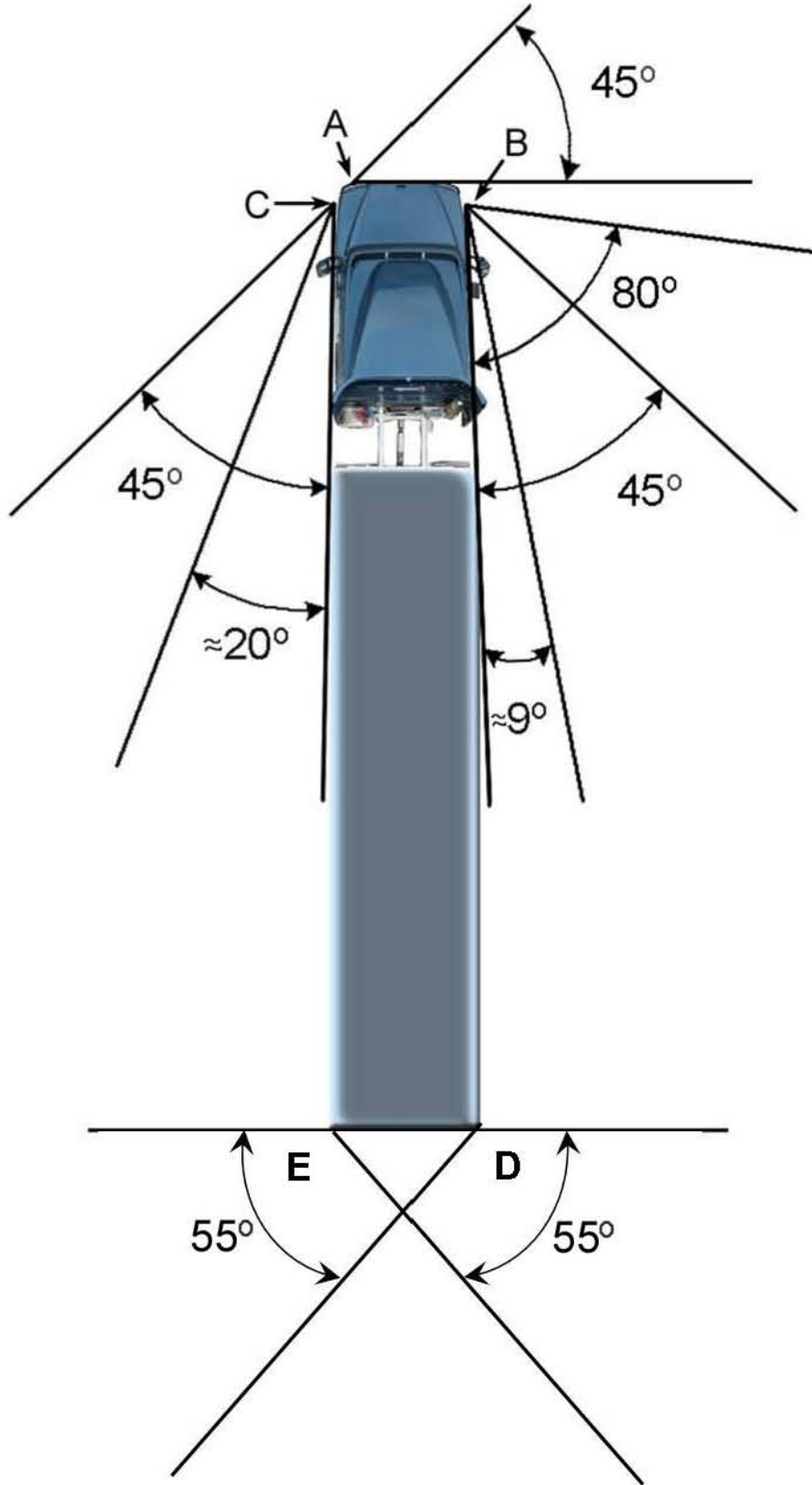


Figure 1. First group of camera locations.

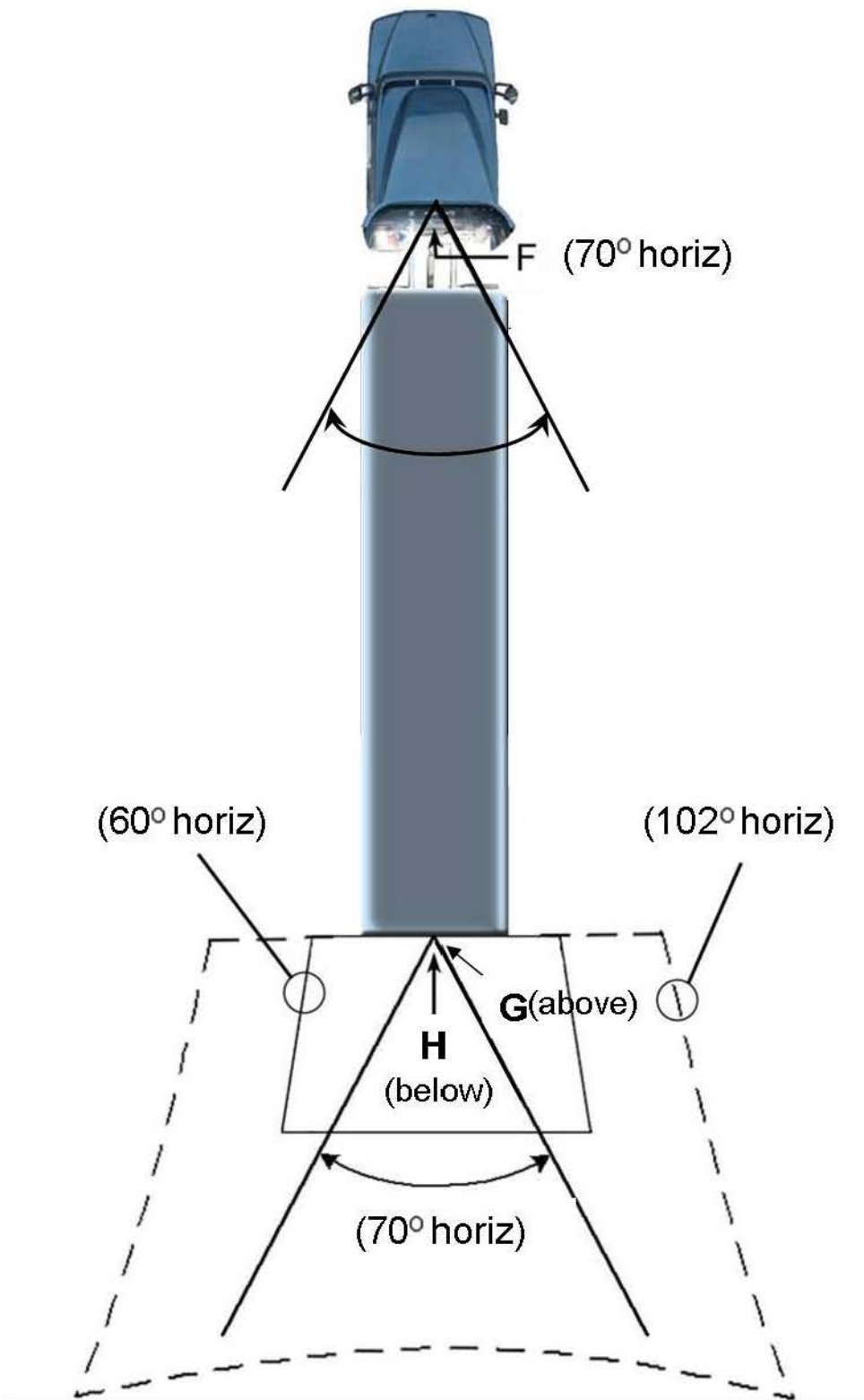


Figure 2. Second group of camera locations.

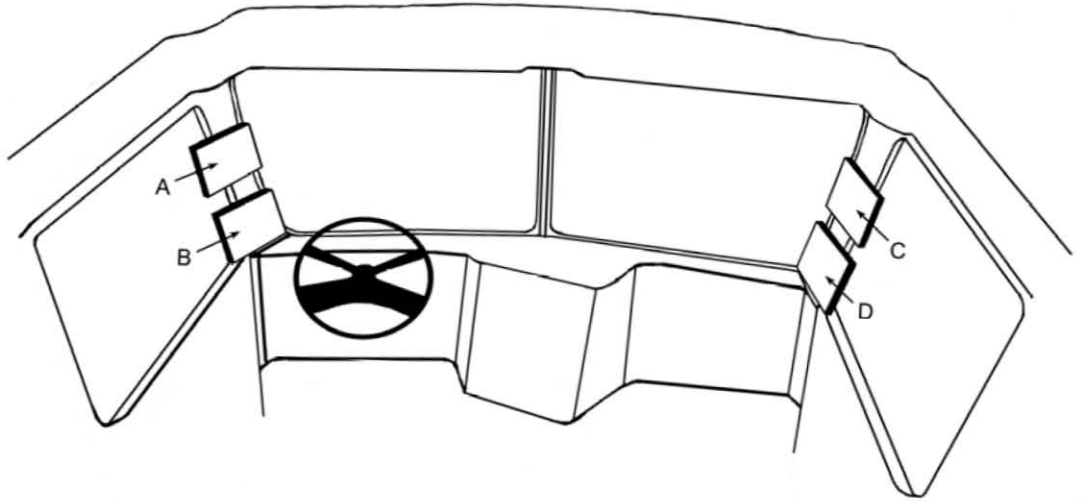


Figure 3. Monitor locations at the A-pillars.

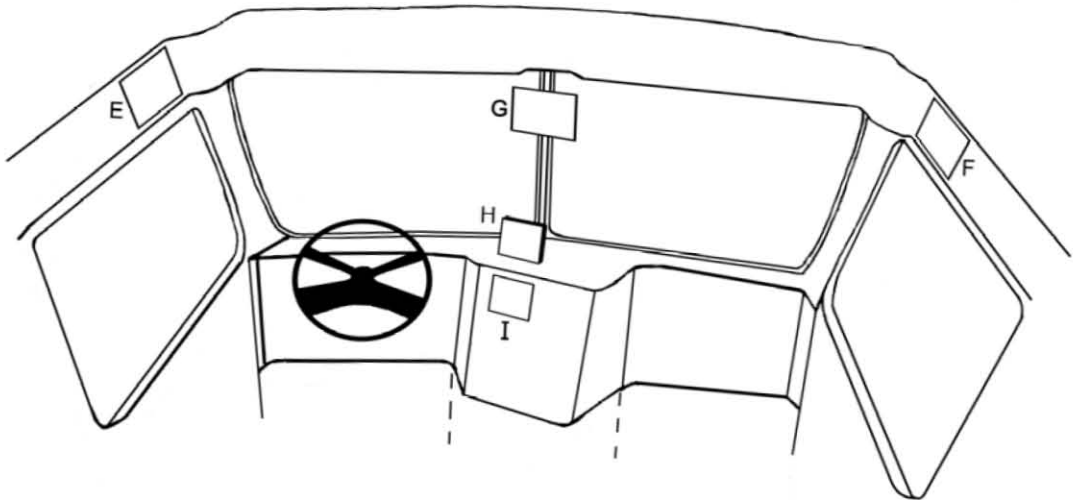


Figure 4. Other monitor locations.

Table 1. Monitor image sizes used in the specifications.

Size Designation	Height	Width	Diagonal
Size 1	8.35 cm 3.29 in	11.3 cm 4.45 in	14.05 cm 5.53 in
Size 2	9.6 cm 3.78 in	12.9 cm 5.08 in	16.1 cm 6.33 in
Size 3	12.8 cm 5.04 in	17 cm 6.69 in	21.3 cm 8.38 in

II A. SURROGATES

Concept Name: Left and Right Flat (West Coast) Mirror Surrogates

Application: Tractor; straight truck cab.

Purpose:

To replace the flat (west coast) mirrors on each side of the tractor/cab. To provide the same coverage and horizontal perspective as the corresponding flat (west coast) mirrors to the extent possible (including two-eyed viewing and look-around capability).

Special Note:

These surrogates may only be implemented if the convex mirror surrogates are also implemented. Flat mirror surrogates may not be used by themselves with actual convex mirrors. The reasons for this are:

1. Flat mirrors are more critical in judging distance and speed, implying that *convex* surrogates are less critical and should be replaced first,
2. Convex mirror surrogates have received favorable ratings and appear to be superior to actual convex mirrors, and
3. Removal of the structure supporting flat and convex mirrors can only occur if both types of mirrors are replaced with surrogates.

It should be noted that the above requirement does not preclude the use of convex mirror surrogates with actual flat mirrors.

Camera location, angle of coverage, aim direction, and focus range:

Left camera: Left front fender mounting, with nominal/initial 20° horizontal FOV.¹

Camera is initially aimed so left edge of camera view is tangent to the front edge of the trailer or cargo box (Figure 1, location C).

Right camera: Right front fender mounting, with nominal/initial 9° horizontal FOV.¹

Camera is initially aimed so right edge of camera view is tangent to the front edge of the trailer or cargo box (Figure 1, location B).

Both cameras should be in sharp focus for objects ranging from 15 to 150 ft (4.6 to 45.7 m).

¹ The best means of field-of-view adjustment is to match image size on the monitor screen to that in an equivalent flat mirror (when viewed from the nominal driver's eye position). A distance of approximately 60 ft (18.3 m) from the mirror to an object (probably a light vehicle) should be used. To perform this operation, a variable focal length (zoom) lens must be installed and adjusted. This lens can then be replaced in production with a lens having the same field-of-view as the setting of the variable focal length lens. This procedure greatly simplifies the problem of obtaining an image with the correct perspective and size. Since the perspective point of view for the C/VIS is lower than for the mirror, the size matching should be done on the basis of the width of the object. See the following section entitled "Detailed Justification and Specifications in Regard to Camera Placement, Camera Field of View, Monitor Placement, and Monitor Field of View."

Monitor location and approximate size:

Left side: Left A-pillar (Figure 3, location B), Size 3.

Right side: Right A-pillar (Figure 3, location D), Size 3.

Image presentation: Reversed scan.²

Activation/Deactivation:

Activate with ignition on. Deactivate with ignition off after 20 s timeout. Driver pushbutton (push on/push off) when the ignition is off. System should deactivate with opening of the driver's door. System may use same pushbutton as convex mirror surrogates, i.e., simultaneous driver control.

Backup:

Because a vehicle cannot be safely operated with a malfunctioning surrogate, a temporary spare mirror and clampable structure should be included with the vehicle. This spare should be designed so it can be used on either the left or the right side of the vehicle and should include a flat mirror of 323 sq. cm. Only one such structure and mirror is required, provided that the left and right surrogates are totally independent systems with separate power supplies. Also, the same structure may contain both a flat and a convex mirror. The temporary spare mirror assembly should be stowed in an accessible position and should have instructions for installation by the driver.

Horizontal Delineator or Distance Aid:

A flat mirror surrogate does not ordinarily provide a stereographic presentation. Therefore, an important depth cue is missing. To help account for this, the monitor should, at a minimum, have a horizontal delineator which designates the end of the trailer on flat roadway. More specifically, it should designate the plane of the rear of the trailer projected to the ground. This line is only dependent on camera aim and not on driver eye position. Therefore, the delineator can be calibrated for an individual cargo load, independent of driver stature and position.

Alternatively, the vehicle may be equipped with left and right merge/re-merge enhancements or the trailer wide-angle, look-down multipurpose enhancement as specified in the section on enhancements. Yet another alternative is to include an electronic side object detection system, so that drivers can determine when the sides of the heavy vehicle are clear of objects.

Vibration Isolation: Because flat mirror surrogates have a narrow FOV, the associated cameras are particularly sensitive to vibration. Mountings for these cameras must be carefully designed and tested to ensure that cameras are isolated sufficiently to produce stable images on their corresponding monitors. Note that since convex mirror surrogates are required when flat mirror surrogates are used, and the cameras have the same location, a common isolation mounting system can be developed.

²Reversed scan in this document implies mirror image presentation; that is, left to right (horizontal) reversal of the image.

Detailed Justification and Specifications in Regard to Camera Placement, Camera FOV, Monitor Placement, and Monitor FOV

Flat mirror surrogates have detailed requirements that are intended to produce images as similar as possible to those of the mirror itself. It should be noted specifically that conventional video chains do not include stereographic presentation, and they do not adjust to the driver's head movements. These factors complicate the design.

Drivers use flat mirrors to judge distance and speed. Consequently, it is considered important to preserve as much of the original perspective and image size as is possible. Aspects to be preserved include:

1. Having the image appear with the equivalent of unit magnification,
2. Preserving correct perspective, and
3. Taking into account the "look-around" and ambinoocular capability of drivers to the extent possible.

Figure 5 shows a side view of the theoretically optimum position that a camera should have to provide exactly the same view as a flat mirror. This position is obtained by projecting the edge lines of the mirror FOV to their intersection. However, since the position is forward of the windshield and other heavy vehicle structures, this position is not practical for camera mounting. Mounting the camera at the fender produces a similar, but lower, view. Specifically, the fender position reduces the blind spot along the side of the heavy vehicle while providing a similar perspective, but with a lower vantage point. It represents the best compromise position for the flat mirror surrogate.

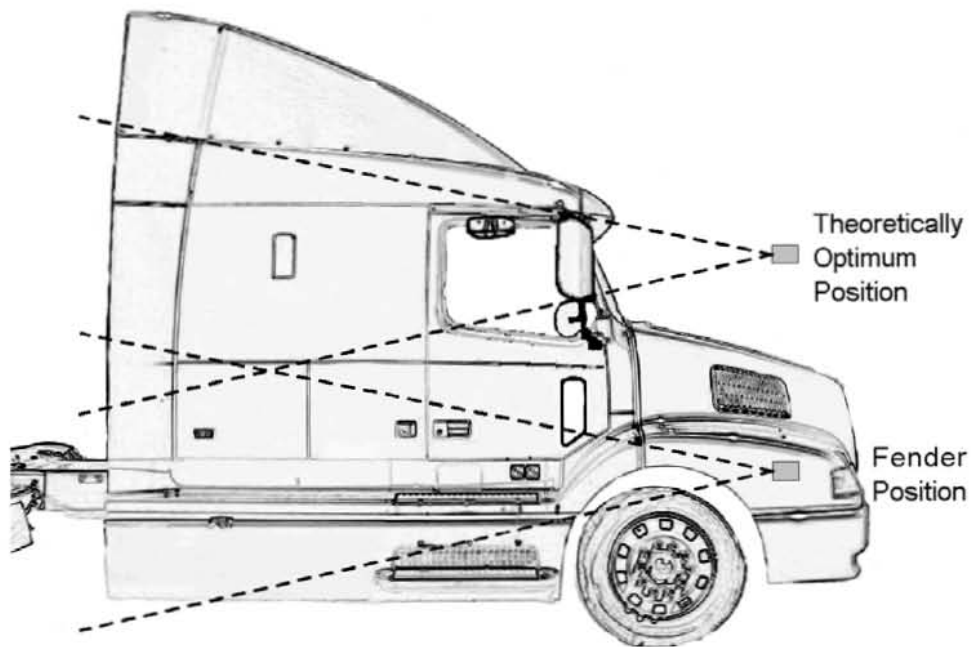


Figure 5. Comparison of theoretically optimum and fender-mount camera positions.

The top view associated with this situation is shown in Figure 6, under the assumption that the driver uses a single eye. The optical path is folded about the mirror, producing a virtual image position that is at the same apparent distance from the mirror as the object is from the mirror. The camera location in Figure 6 produces an image with exactly the same perspective. To view this image in full size, the monitor is placed at the position of the mirror and is oriented toward the driver's eye.

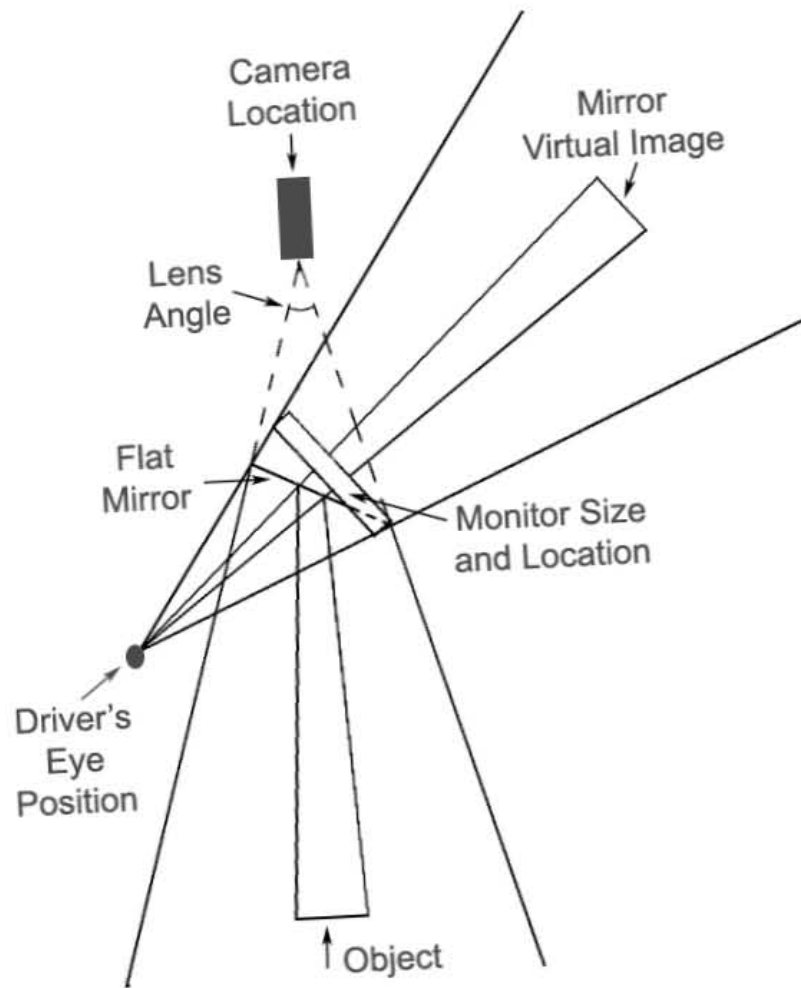


Figure 6. Hypothetical equivalent video system for a mirror.

Monitor size for correct image size must be adjusted according to viewing distance. Figure 7 shows that as the monitor is moved closer to the driver, its size must decrease and, similarly, as the monitor is moved away from the driver, its size must increase. The monitor size is always chosen so that the angular subtense of the image at the eye is preserved.

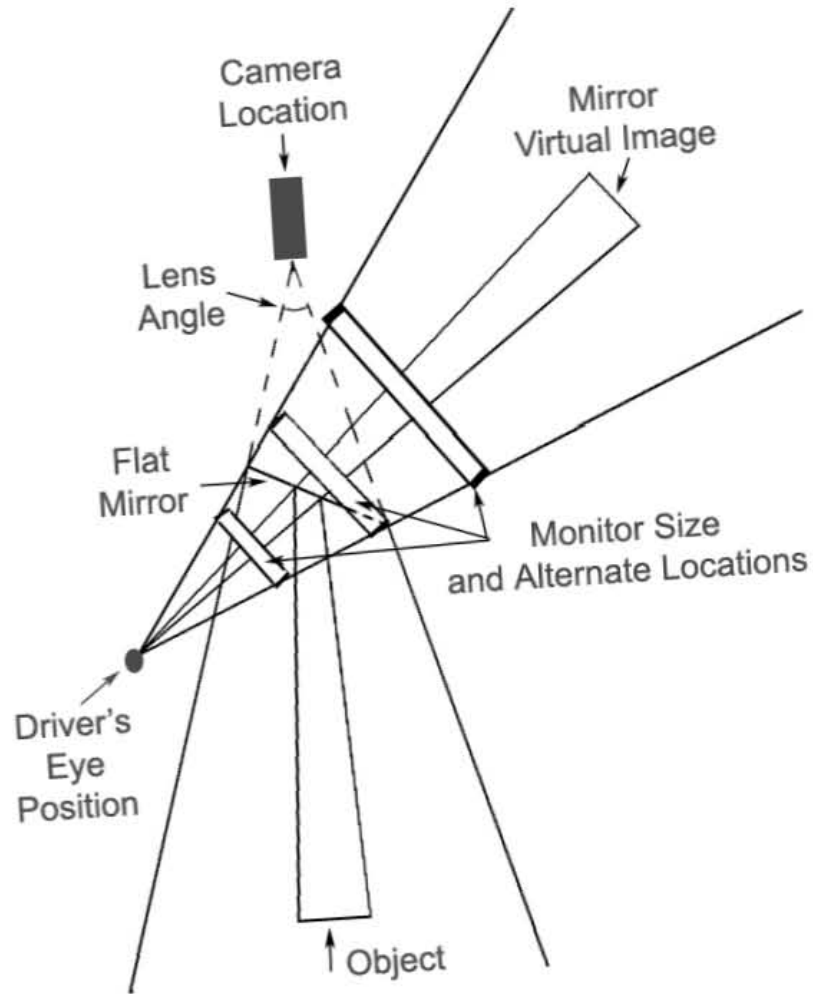


Figure 7. Equivalent monitor locations for a mirror surrogate video system.

The driver ordinarily views the mirror using both eyes, that is, ambbinocularly. The left eye and the right eye then have slightly different perspectives and FOVs, as shown in Figure 8. The effect of this is to increase the equivalent FOV somewhat. It is estimated that for the passenger side mirror this increase is about 2° , whereas for the driver side mirror the increase is about 4° . The difference in these values is a result of the difference in nominal distance of the driver's eyes to the mirrors. It is desirable to account for these increased FOVs by using camera lenses with larger FOVs and monitors that are similarly larger.

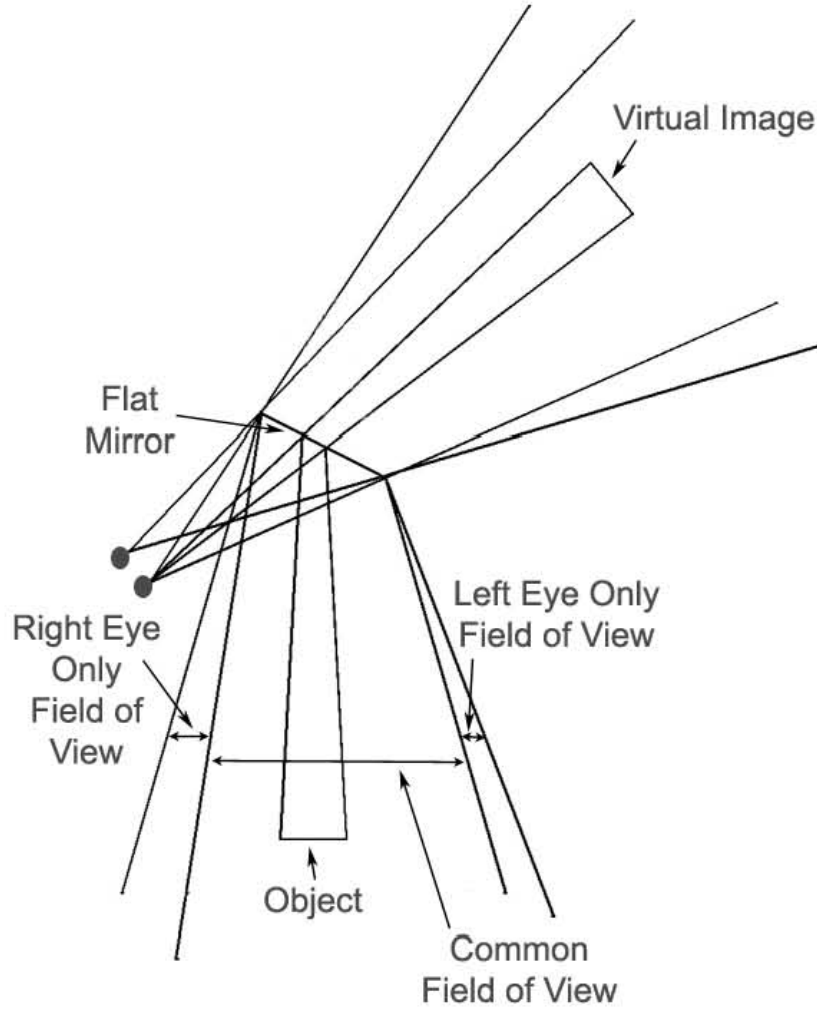


Figure 8. FOV for ambinoocular vision.

An additional factor that must be considered is look-around capability. Drivers often move their heads to increase detection probability. Moving the head forward causes the FOV to shift outward (away from the vehicle), while moving the head back causes the FOV to shift inward (toward the vehicle). It has been estimated that the driver can increase the FOV for the passenger side mirror by 3° and can increase the FOV of the driver side mirror by 5.5°. Again, note that conventional video would not account for these head movements. Therefore, the lens FOV and monitor should be increased in size accordingly.

Measurements from actual vehicles indicate that when all factors are taken into account, the average equivalent FOV for the passenger side mirror is 9° and the average equivalent FOV for the driver side mirror is 20°. These values are the design goals for the

corresponding C/VISs. The values are relatively large and can cause difficulties with regard to monitor size, in that the monitors to obtain these FOVs may be relatively large.

To calculate monitor width for an image to appear in true size and with correct perspective, the equation is as follows:

$$w = 2d \tan \frac{\theta}{2}$$

where w is the horizontal width of the monitor, d is the nominal viewing distance, and θ is the camera horizontal FOV. The values of w and d must be in the same units of distance.

Table 2 shows monitor size as a function of typical viewing distances, assuming the passenger side FOV is 9° and the driver side FOV is 20°. In this table, monitor width is considered the primary measurement. The table shows that monitors become excessively large; that is, they exceed 8.5 in (21.6 cm) in width, for viewing distances greater than 24 in (61.0 cm) on the left (driver) side and greater than 54 in (137.2 cm) on the right (passenger) side. Even so, monitors with widths of 8.5 in (21.6 cm) are relatively large and are difficult to integrate into the structure of the vehicle cab. Therefore, compromise is necessary.

Table 2. Monitor screen width as a function of distance from the driver's eyes.

Side	Angular subtense (degrees)	Viewing distance (inches)	Monitor width (inches)
Left	20	12	4.23
		18	6.35
		24	8.46
		30	10.6
		36	12.7

Right	9	48	7.6
		54	8.5
		60	9.4
		66	10.4
		72	11.3

The specifications for monitor locations given previously indicate that the monitors should be placed over the A-pillars. This location has been chosen because it minimizes blind spots while maintaining the same approximate direction of glance as the conventional flat mirrors, thereby facilitating driver transition to and from a surrogate-equipped vehicle. If there is overlap, it should be to the rear, so that the windshield is not obstructed.

It may become necessary to use a slightly smaller monitor for practical reasons such as safety or mechanical mounting considerations. If so, image size and perspective are to be maintained by reducing camera FOV.

To maintain image size and perspective, the following equation can be used to determine camera horizontal FOV for a given monitor width:

$$\theta = 2 \arctan \frac{w}{2d}$$

Camera aiming is an important consideration when using cameras with narrow FOVs. There are two possibilities in regard to aiming:

1. Aim the camera so the inside edge of the FOV is just tangent to the front edge of the trailer/cargo box, or
2. Aim the camera so that it is centered in the adjacent lane at a point that is projected sideways at the back end of the trailer/cargo box.

The latter should be considered if the camera FOVs are smaller than the design goal values. Compromises that combine the above possibilities should also be considered.

As an earlier footnote indicated, once the monitor is selected (Size 3 was specified), the best procedure is to use an adjustable (zoom) telephoto lens temporarily. The image horizontal dimension at 60 ft (18.3 m) can then be matched to an image in an actual temporary flat mirror. Once the FOV is known, it can be matched using a fixed focal length lens. This procedure will ensure correct image size, regardless of monitor size.

Concept Name: Convex Left- and Right-Side Mirror Surrogates

Application: Tractor; straight truck cab.

Purpose:

To replace the convex mirrors on each side of the tractor/cab. To provide coverage that is approximately the same as the corresponding convex mirrors.

Camera location, angle of coverage, aim direction, and focus range:

Left camera: Left front fender mounting, with 45° horizontal FOV.³ Camera is aimed so left edge of camera view (prior to image reversal) is tangent to the front edge of the trailer or cargo box (Figure 1, location C).

Right camera: Right front fender mounting, with 45° horizontal FOV*. Camera is aimed so right edge of camera view (prior to image reversal) is tangent to the front edge of the trailer or cargo box (Figure 1, location B.)

Both cameras should be in sharp focus for objects ranging from 10 to 120 ft (3.0 to 36.6 m).

Monitor location and approximate size:

Left side: Left A-pillar (Figure 3, location A), Size 2.

Right side: Right A-pillar (Figure 3, location C), Size 2.

Note that if flat mirror surrogates are not being implemented, locations B and D (Figure 3) can be used.

Image presentation: Reversed scan.

Activation/Deactivation:

Activate with ignition on. Deactivate with ignition off after 20 s timeout. Driver pushbutton (push on/push off) when the ignition is off. System should deactivate with opening of the driver's door. System may use same pushbutton as flat mirror surrogates, i.e., simultaneous driver control, if both convex and flat mirrors are being replaced with surrogates.

Backup:

Because a vehicle cannot be safely operated with a malfunctioning surrogate, a temporary spare mirror and clampable structure should be included with the vehicle. This spare should be designed so it can be used on either the left or the right side of the vehicle and should include a convex mirror. Only one such structure and mirror are required, provided that the left and right surrogates are totally independent systems with separate power supplies. Also, the same structure may contain both a convex and a flat mirror. The temporary spare mirror assembly should be stowed in an accessible position and should have instructions for installation by the driver.

³ See the following section titled "Justification and Specifications in Regard to Camera Placement, Camera Field of View, Monitor Placement, and Monitor Size."

Justification and Specifications in Regard to Camera Placement, Camera FOV, Monitor Placement, and Monitor Size

As in the case of the flat mirror surrogates, the equivalent position for the convex mirror surrogate camera is out in front of the vehicle, but not as far in front. Nevertheless, the best available camera position is at the front fender. This position lowers the vantage point, but reduces the blind spot along the side of the vehicle.

Fields of view have been measured for typical convex mirrors. Taking binocular view and look-around capability into account, these fields are about 45° on each side of the vehicle. (While the right side is slightly narrower, it is not appreciably narrower. For that reason, the common specification of 45° has been selected.) The cameras should be aimed so that the inside edge of the FOV is tangent to the front edge of the trailer/cargo box. This aiming provides best coverage.

Convex mirrors are used primarily for object detection and, possibly, approximate angular location. Consequently, monitors in convex mirror surrogates need not (and should not) produce images in true size. Correspondingly, monitor size selection should be based on adequacy of image size at the given viewing distance. In the previous section entitled “Monitor location and approximate size”, the monitors for left and right convex mirror surrogates were specified as Size 2. This size is larger than most convex mirrors when they are angled relative to the driver. The monitor locations indicate that the monitors should be placed over the A-pillars. This location has been chosen because it minimizes blind spots while maintaining the same approximate direction of glance as the conventional flat mirrors, thereby facilitating driver transition to and from a surrogate-equipped vehicle. If there is overlap, it should be to the rear, so that the windshield is not obstructed.

II B. ENHANCEMENTS

Concept Name: Front Blind-Spot Enhancement

Application: Tractor; straight truck.

Purpose:

To provide coverage of the blind spot perceived to exist at the right (passenger) front of the tractor/cab, for use in yard/urban situations.

(This system is only useful while standing or moving at speeds well below 5 mph [8.1 km/h]).

Camera location, angle of coverage, aim direction, and focus range: Left front bumper mounting, with 45° horizontal FOV. Camera is aimed such that the right edge of camera view is tangent to the bumper (Figure 1, location A). The right edge of the camera FOV should include the vehicle's vertical radiator housing as a landmark. The driver can then use this landmark as a means of orienting to the scene. Camera should be in sharp focus for objects ranging from 4 to 25 ft (1.2 to 7.6 m).

Monitor location and approximate size: In or above center dash area (Figure 4, location H or I, with H preferred), Size 1.

Image presentation: Standard (un-reversed) scan.

Activation/Deactivation: A driver's pushbutton should activate/deactivate this enhancement. However, at speeds above 5 mph (8.1 km/h), the system should automatically deactivate. These functions should be separate in the sense that if the speed again goes below 5 mph (8.1 km/h) the system should re-activate, assuming the driver's pushbutton remains activated. This system should be available for use whenever the vehicle ignition is on.

Backup: Not required.

Coordination:

This enhancement can be combined with the tractor rear backing/bobtailing enhancement and with the trailer rear-view enhancement. When the tractor is uncoupled, it could switch between the front blind-spot enhancement and the tractor rear backing/bobtailing enhancement. When the tractor is connected to a trailer, it could switch between the front blind-spot enhancement and the trailer rear-view enhancement. Switching could be made automatic at a forward speed of 5 mph (8.1 km/h), with manual override by the driver.

Concept Name: Right-Side Wide-Angle Blind-Spot Enhancement

Application: Tractor; straight truck cab.

Purpose: To provide complete coverage of the blind spot perceived to exist all along the right (passenger) side of the tractor or cab.

Camera location, angle of coverage, aim direction, and focus range: Right front fender mounting, with 80 to 90° horizontal FOV. Camera is aimed so right edge of camera view is tangent to the tractor/cab (Figure 1, location B). Camera should be in sharp focus for objects ranging from 10 to 130 ft (3.05 to 39.6 m).

Monitor location and approximate size:

In or above center dash area (Figure 4, locations H or I), Size 1.

Alternative location: Base of right A-pillar, assuming surrogates are not used (Figure 3, location D), Size 2. Second alternative location: Right side header (Figure 4, location F).

Image presentation: Reversed scan.

Activation/Deactivation:

Alternative 1. Activate with ignition on. Deactivate with ignition off after 20 s timeout. Driver pushbutton (push on/push off) when the ignition is off. Pushbutton should release/deactivate with opening of the driver's door. (May use same pushbutton as mirror surrogates; i.e., simultaneous driver control, if vehicle is equipped with one or more mirror surrogates.)

Alternative 2. A driver's pushbutton switch should activate/deactivate this enhancement. This system should be available for use whenever the vehicle ignition is on.

Backup: Not required.

Concept Name: Left-Side Blind-Spot Enhancement

Application: Tractor; straight truck cab.

Purpose: To provide complete coverage of the blind spot perceived to exist along the left side of the tractor or cab from the driver's door to the rear.

Camera location, angle of coverage, and aim direction: Left front fender mount with 45° horizontal FOV. Camera is aimed so left edge of camera view is tangent to the tractor or cargo box (Figure 1, location C). (Note that this camera has the same specifications as the left convex mirror surrogate camera.)
Camera should be in sharp focus for objects ranging from 10 to 150 ft (3.0 to 45.7 m).

Monitor location and approximate size: Left A-pillar (Figure 3, location B), Size 2, assuming flat mirror surrogate is not implemented. Note that if convex surrogate is used, this enhancement view is identical to the surrogate view. An additional monitor is not needed. Note also that if flat mirror surrogates are not implemented, locations A or B can be used.

Image presentation: Reversed scan.

Activation/Deactivation:

Alternative 1. Activate with ignition on. Deactivate with ignition off after 20 s timeout. Driver pushbutton (push on/push off) when the ignition is off. System should deactivate with opening of the driver's door. System may use same pushbutton as surrogates, if they are implemented.

Alternative 2. A driver's pushbutton switch should activate/deactivate this enhancement. This system should be available for use whenever the vehicle ignition is on. This alternative should be used when no surrogates are implemented.

Backup: Not required, except that convex mirror surrogate requires backup, as previously specified.

Concept Name: Tractor Rear Backing/Bobtailing Enhancement

Application: Tractor.

Purpose: To provide a view directly behind the tractor, for backing and parking in yard/urban situations, and to provide a rear view similar to a rear-view mirror when driving on-road. This concept is for use in the uncoupled mode only.

Camera location, angle of coverage, aim direction, and focus range: Center rear of tractor cab at a height of 8 to 9 ft (2.43 to 2.75 m) above the pavement, aimed rearward. The camera horizontal FOV is 70°. The camera is aimed downward somewhat so that both the horizon and the rear wheels are within the vertical FOV (Figure 2, location F). Camera should be in sharp focus for objects ranging from 12 to 150 ft (3.7 to 45.7 m).

Monitor location and approximate size:

Upper center of windshield (Figure 4, location G), Size 2.

Alternative locations: In or above center dash area (Figure 4, locations H and I), Size 1.

Image presentation: Reversed scan.

Activation/Deactivation: A driver's pushbutton switch should activate/deactivate this enhancement. This system should be available for use whenever the vehicle ignition is on.

Note that this enhancement can be combined with the trailer rear-view enhancement. When a trailer is attached, the camera switches to the trailer camera. When there is no trailer, the tractor backing/bobtailing camera specified above is used.

Backup: Not required.

Coordination:

This enhancement can be combined with the front blind-spot enhancement and with the trailer rear-view enhancement. When the tractor is uncoupled, it could switch between the front blind-spot enhancement and the tractor rear backing/bobtailing enhancement. When the tractor is connected to a trailer, it could switch between the front blind-spot enhancement and the trailer rear-view enhancement. Switching could be made automatic at a forward speed of 5 mph (8.05 km/h), with manual override by the driver.

Concept Name: Left and Right Merge/Re-Merge Enhancements

Application: Trailer; cargo box.

Purpose: To provide a positive view of the trailer/cargo box clearance when merging or re-merging to the left or right. This view shows the relationship (amount of clearance or overlap) between a vehicle being passed and rear end of the trailer/cargo box.

Camera location, angle of coverage, aim direction, and focus range:

Right Merge/Re-merge Camera: Left rear corner of the trailer/cargo box with 55° horizontal FOV. Camera is aimed so that the left edge of the camera view includes the right rear vertical edge of the trailer/cargo box (Figure 1, location E). Camera is mounted approximately 7 ft (2.1 m) above the road level.

Camera should be in sharp focus for objects ranging from 8 to 40 ft (2.4 to 12.2 m).

Left Merge/Re-merge Camera: Right rear corner of the trailer/cargo box with 55° horizontal FOV. Camera is aimed so that the right edge of the camera view includes the left rear vertical edge of the trailer/cargo box (Figure 1, location D). Camera is mounted approximately 7 ft (2.1 m) above the road level.

Camera should be in sharp focus from 8 to 40 ft (2.4 to 12.2 m).

Monitor location and approximate size:

Right Merge/Re-merge enhancement: Right header (Figure 4, location F), Size 2.

Left Merge/Re-merge enhancement: Left header (Figure 4, location E), Size 2.

Note that both monitors should be placed as far forward on the side headers as possible to minimize neck strain.

Image presentation: Standard (un-reversed) scan.

Activation/Deactivation with combined flat and convex surrogates: If the merge/re-merge enhancements are implemented as part of the package used with combined flat and convex mirror surrogates, then activation and deactivation should be the same as the combined surrogates.

Activation/Deactivation, Other: A driver's pushbutton switch should activate/deactivate this enhancement. This system should be available for use whenever the vehicle ignition is on.

Backup: Not required.

Concept Name: Trailer Rear-View Enhancement

Application: Trailer; cargo box.

Purpose: To provide a view similar to a rear-view mirror, directly behind the trailer/cargo box. To provide a view of the situation behind the vehicle while traveling at highway speeds.

Camera location, angle of coverage, aim direction, and focus range: Camera is mounted at the rear of the trailer/cargo box near the vertical centerline at a height of 8 to 9 ft (2.43 to 2.75 m) above the pavement, aimed rearward. The camera horizontal FOV is 70°. The camera is aimed downward somewhat so that the horizon is in view at the top of the camera scene (Figure 2, location H). Camera should be in sharp focus for objects ranging from 12 to 150 ft (3.7 to 45.7 m).

Monitor location and approximate size:

Upper center of windshield (Figure 4, location G), Size 2.

Alternative locations: In or above center dash area (Figure 4, locations H and I, with H preferred), Size 1.

Image presentation: Reversed scan.

Activation/Deactivation: A driver's pushbutton switch should activate/deactivate this enhancement. This system should be available for use whenever the vehicle ignition is on.

Backup: Not required.

Coordination:

This enhancement can be combined with the front blind-spot enhancement and with the tractor rear backing/bobtailing enhancement. When the tractor is uncoupled, it could switch between the front blind-spot enhancement and the tractor rear backing/bobtailing enhancement. When the tractor is connected to a trailer, it could switch between the front blind-spot enhancement and the trailer rear-view enhancement. Switching could be made automatic at a forward speed of 5 mph (8.05 km/h), with manual override by the driver.

Concept Name: Trailer Rear Look-Down Enhancement

Application: Trailer; cargo box.

Purpose: To provide a view directly behind the trailer/cargo box, for backing and parking in yard/urban situations.

Camera location, angle of coverage, aim direction, and focus range:

Rear top center of the trailer or cargo box, aimed downward so that the bottom edge of the camera view includes to the rear vertical surface of the trailer or cargo box. The camera itself has a 60° (horizontal) FOV. Note that the horizontal dimension is the one that is tangent to the rear surface of the trailer (Figure 2, location G).

Camera should be in sharp focus for objects ranging from 5 to 40 ft (1.5 to 12.2 m).

Monitor location and approximate size:

Upper center of windshield (Figure 4, location G), Size 2.

Alternative locations: In or above center dash area (Figure 4, locations H and I), Size 1.

Image presentation: Reversed scan.

Activation/Deactivation: A driver's pushbutton switch should activate/deactivate this enhancement. This system should be available for use whenever the vehicle ignition is on.

Backup: Not required.

Concept Name: Wide-Angle Trailer Rear Multipurpose Look-Down Enhancement

Application: Trailer; cargo box.

Purpose: To provide a multifunction rear view used for the following purposes:

1. To provide a view directly behind the trailer/cargo box, for backing and parking in yard/ urban situations.
2. To provide a view of the traffic situation behind the trailer/cargo box for use in highway driving (note that the view does not go out to the horizon).
3. To provide a view of the adjacent left lane for purposes of showing rear clearance when merging to the left.
4. To provide a view of the adjacent right lane for purposes of showing rear clearance when merging to the right.

Camera location, angle of coverage, and aim direction:

Rear top center of the trailer or cargo box, aimed downward so that the bottom edge of the camera view includes the rear vertical surface of the trailer or cargo box. The camera itself has a 102° (horizontal) FOV. Note that the horizontal dimension is the one that is tangent to the rear surface of the trailer (Figure 2, location G).
Camera should be in sharp focus for objects ranging from 6 to 80 ft (1.83 to 24.4 m).

Monitor location and approximate size:

Upper center of windshield (Figure 4, location G), Size 2.
Alternative locations: In or above center dash area (Figure 4, locations H and I), Size 1.

Image presentation: Reversed scan.

Activation/Deactivation: A driver's pushbutton switch should activate/deactivate this enhancement. This system should be available for use whenever the vehicle ignition is on.

Activation/Deactivation with combined flat and convex surrogates: If the wide-angle trailer rear multipurpose enhancement is implemented as part of the package used with combined flat and convex surrogates, then activation and deactivation should be the same as the combined surrogates. This will require that the enhancement be activated whenever the vehicle is in operation.

Activation/Deactivation, Other: A driver's pushbutton switch should activate/deactivate this enhancement. This system should be available for use whenever the vehicle ignition is on.

Backup: Not required.

Image Distortion: Because of the wide-angle lens used with this enhancement, there will be noticeable image distortion appearing on the monitor. However, tests have shown that drivers can use this system for its intended purposes. Image remapping may be used, but should be tested to ensure that it does not have detrimental effects on performance.

Concept Name: Trailer Rear Multi-Camera Enhancement

Application: Trailer; cargo box.

Purpose: To provide four rear views each used for a different purpose:

- Camera 1. To provide a view directly behind the trailer/cargo box, for backing and parking in yard/urban situations.
- Camera 2. To provide a view similar to a rear-view mirror, directly behind the trailer/cargo box. To provide a view of the situation behind the heavy vehicle at on-road speeds.
- Camera 3. To provide a view of the adjacent left lane for purposes of showing rear clearance when merging to the left.
- Camera 4. To provide a view of the adjacent right lane for purposes of showing rear clearance when merging to the right.

Camera locations, angles of coverage, aim directions, and ranges of sharp focus:

Research and development associated with this enhancement have shown that four previously specified enhancements should be used to fulfill the requirements of this enhancement. They are:

- Camera 1. Trailer rear look-down enhancement
- Camera 2. Trailer rear-view enhancement
- Camera 3. Left merge/re-merge enhancement
- Camera 4. Right merge/re-merge enhancement

Monitor locations and approximate sizes: The locations and sizes previously specified for the above designated enhancements should be used.

Image presentation: Reversed scan for Cameras 1 and 2; Standard (un-reversed) scan for Cameras 3 and 4.

Activation/Deactivation: For the two merge/re-merge enhancements, use the activation/deactivation specifications stated for those enhancements. For the trailer rear look-down and trailer rear-view enhancements, a pushbutton arrangement should be used which allows the driver to switch between the two views or to deactivate them. The system should be available whenever the ignition is on.

Backup: Not required.

III. ADDITIONAL COMMON DETAILED SPECIFICATIONS

There are additional detailed specifications that are common to either the surrogate concepts or the enhancement concepts or both. These specifications are presented in this section. They represent aspects not yet covered or not covered in detail previously. As indicated earlier, specifications for surrogates are often somewhat tighter than those of enhancements.

System Operating Temperature Range; Exposure Temperature Range

Surrogates: All exterior components should be operational over a temperature range of -25 to 120° F (-31.7 to 48.9° C). All cab interior components should be operational over a temperature range of -5 to 110° F (-20.6 to 43.3 degrees C). All components should be capable of withstanding sustained exposure temperatures of -30 to 150° F (-34.4 to 65.6 degrees C).

Enhancements: All exterior components should be operational over a temperature range of -10 to 120° F (-23.3 to 48.9° C). All cab interior components should be operational over a temperature range of 0 to 110° F (-17.8 to 43.3° C). All components should be capable of withstanding sustained exposure temperatures of -30 to 150° F (-34.3 to 65.6° C).

Exterior Illumination Operating Range

All cameras should be capable of providing a usable image for objects with luminances in the range from 0.02 to 20,000 cd/m² (0.0058 to 5831 ft.l.). Cameras should use automatic gain control (AGC) and possibly auto-iris functions to achieve acceptable image quality and, if necessary, to protect them from bright sources.

Cab Interior Illumination Operating Range

Monitors should be capable of providing appropriate luminance and contrast for monitor screen incident illumination levels as follows:

Monitors at the A-pillars (all monitors depicted Figure 3): 5 to 6,000 lux (0.46 to 557 ft.c.)

Monitors in or above the center dash (locations G, H, and I in Figure 4): 5 to 5,000 lux (0.46 to 465 ft.c.)

Monitors on the side headers (locations E and F in Figure 4): 5 to 3,500 lux (0.46 to 325 ft.c.).

Monitors may use glare reduction filters over screens.

Monitors may use hooding to reduce the probability of sunlight or other bright sources from appearing on the monitor screen. Hooding, if used, should be designed so that it does not present a hazard to the driver or passenger in either normal or collision situations. Furthermore, hooding should not appreciably increase blind spots.

Monitor Luminance/Contrast Adjustment

Monitor luminance and contrast should adjust automatically over the above ranges to provide an image that is appropriate for the incident illuminance. The driver should be provided with a single control having a center position that provides the nominal automatic setting. The control should be movable in either direction, allowing the driver to increase or decrease the nominal automatic setting. The control should simultaneously adjust brightness and contrast appropriately so that driver distraction during adjustment is minimized. The control should not require extended reach by the driver and should be close to any other activation/deactivation/selection pushbuttons associated with the implemented concept or concepts.

Monitor Luminance Fluctuation

Monitor luminance must not change abruptly because doing so will distract the driver. Such fluctuation can be caused by camera AGC or auto-iris that responds too rapidly, is too close to instability, or is malfunctioning. Similarly, jumps in monitor luminance resulting from faulty wiring or termination must be avoided. At the same time, monitor luminance should adjust appropriately, but slowly, to actual changes in luminance associated with the camera scene.

System Minimum Image Resolution

Surrogates: 400 horizontal TV lines or 640 horizontal pixels

Enhancements: 350 horizontal TV lines or 540 horizontal pixels

Note that in many cases, smaller flat panel monitors are not capable of providing the image resolution specified. In such cases, the design goal should be to provide a video signal with the above resolution with the eventual intent of obtaining monitors capable of full utilization of the signal.

System Refresh Rate

Nominal 60 frames per second, interlaced (30 full frames per second), or nominal 60 frames per second (progressive scan).

System Maximum Image Delay

50 ms from object movement in front of camera to corresponding screen image movement.

System Persistence

Persistence should be selected so that there is negligible flicker with a dark surround using peripheral vision (defined as having the monitor 75° away horizontally from the straight ahead position). However, persistence should not be longer than necessary, because it can affect total system image delay.

System Reliability

Surrogates: Mean time between failures of 5,000 h under real or simulated operational conditions.

Enhancements: Mean time between failures of 3,000 h under real or simulated operational conditions.

Vibration and Shock Immunity

Cameras and monitors should use mountings and structures under the mountings that minimize image smear and jumping due to vibration. Image stabilization may also be used. The system reliability specification is to include vibration and shock as normally encountered in driving.

Response to Activation

Upon activation by the driver, the corresponding system should provide a viewable, stable image within 400 ms. The monitor should not have an initial luminance flash.

Image Aspect Ratio

The specifications call for the use of monitors with an aspect ratio of 3 units of height to 4 units of width. If a manufacturer wishes to use a different aspect ratio, approval should be obtained from NHTSA using supporting documentation.

REFERENCE

Wierwille, W. W., Schaudt, W. A., Spaulding, J. M., Gupta, S. K., Fitch, G. M., Wiegand, D. M., & Hanowski, R. J. (June 2007). *Development of a performance specification for camera/video imaging systems on heavy vehicles: final report, supporting research*. (Contract DTNH22-05-D-01019, Task Order 5, Track 2). Blacksburg, VA: Virginia Tech Transportation Institute.

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