THE ABILITY OF REAR-MOUNTED CONVEX MIRRORS TO IMPROVE REAR VISIBILITY

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ABSTRACT

The Cameron Gulbransen Kids Transportation Safety Act of 2007 requires the National Highway Traffic Safety Administration (NHTSA) to "initiate a rulemaking to revise Federal Motor Vehicle Safety Standard 111 to expand the required field of view to enable the driver of a motor vehicle to detect areas behind the motor vehicle to reduce death and injury resulting from backing incidents, particularly incidents involving small children and disabled persons." It goes on to state that this may be accomplished "by the provision of ***additional mirrors*** (emphasis added), sensors, cameras, or other technology to expand the driver's field of view." An advanced notice of proposed rulemaking was published on February 27, 2009. This paper examines whether rear-mounted convex mirrors could provide an image with sufficient quality that may be useful in aiding drivers in performing backing maneuvers.

There are three main configurations of rear-mounted convex mirrors: a single "look-down" mirror, a single corner mirror, and a pair of cross-view mirrors. NHTSA measured fields of view and image quality of one look-down mirror and three pairs of cross-view mirrors for passenger vehicle applications. Field of view and image quality were also estimated for one rear convex corner mirror based on previous research with that mirror relating to its use on medium straight trucks. Note that this study did not attempt to examine whether drivers will successfully use rear-mounted convex mirrors to successfully detect obstacles or pedestrians behind a vehicle. This question of potential overall effectiveness of rear-mounted convex mirrors, relative to other solutions to expand the driver's rear field of view, will be the subject of additional agency research.

The useful fields of view (FOV) of the five rear-mounted convex mirrors were determined. The potential backover risk reductions were estimated for the five mirrors studied, using only that portion of their FOV's with an image quality rating of better than "impossible." The estimated potential backover risk reductions ranged from 33.4 percent (for the Toyota 4Runner rear cross-view mirrors) to 2.2 percent (for the ScopeOut™ passenger car rear cross-view mirror).

INTRODUCTION

The Cameron Gulbransen Kids Transportation Safety Act of 2007 requires the National Highway Traffic Safety Administration (NHTSA) to "initiate a rulemaking to revise Federal Motor Vehicle Safety Standard 111 to expand the required field of view to enable the driver of a motor vehicle to detect areas behind the motor vehicle to reduce death and injury resulting from backing incidents, particularly incidents involving small children and disabled persons." It goes on to state that this may be accomplished "by the provision of ***additional mirrors*** (emphasis added), sensors, cameras, or other technology to expand the driver's field of view." An advanced notice of proposed rulemaking (ANPRM) that summarizes relevant research and outlines some of NHTSA ideas regarding how to respond to the Act was published on February 27, 2009. This paper examines whether rear-mounted convex mirrors provide an image with sufficient quality that may be useful in aiding drivers to identify and avoid rear obstacles.

THE SAFETY PROBLEM

In response to earlier legislation, NHTSA developed the Not in Traffic Surveillance (NiTS) system to collect information about all nontraffic crashes, including nontraffic backing crashes. NiTS provided information on backing crashes that occurred off the traffic way and which were not included in NHTSA's Fatality Analysis Reporting System (FARS) or the National Automotive Sampling System - General Estimates System (NASS-GES).

Based on NiTS, NHTSA estimates that 463 fatalities and 48,000 injuries a year occur in traffic and nontraffic backing crashes [1]. Most of these injuries are minor, but an estimated 6,000 per year are incapacitating injuries. Overall, an estimated 65 percent (302) of the fatalities and 62 percent (29,000) of the injuries in backing crashes occurred in nontraffic situations.

Table 1 shows the fatalities and injuries in all backing crashes. Backover crashes account for an estimated 63 percent (292) of the fatalities and 38 percent (18,000) of the injuries in backing crashes for all vehicles (cars, light trucks or vans, heavy trucks, and other/multiple vehicles). Other backing crash scenarios account for an estimated 171 fatalities (37 percent) and 30,000 injuries (62 percent) per year.

Table 1: Fatalities and Injuries Due to Backing (All Vehicles)

	All Backing Crashes	Backover Crashes	Non-Backover Crashes
Fatalities	**463**	**292**	**171**
Injuries	**48,000**	**18,000**	**30,000**
Severe	6,000	3,000	3,000
Minor	12,000	7,000	5,000
Possible	27,000	7,000	20,000
Unknown	2,000	1,000	2,000

Note: Numbers may not add to totals due to rounding.

OBJECTIVES OF THIS RESEARCH

Backover crashes are defined as backing crashes in which the backing vehicle strikes a pedestrian or pedacyclist. Frequently this occurs because a driver did not see the person and was therefore unaware of their presence. All vehicles have "blind areas" behind them in which certain sizes of pedestrians cannot be seen by drivers either through direct vision or by looking in the rearview mirrors. Improving drivers' rear visibility so as to "fill-in" these blind areas may aid in reducing backover crashes.

Adding rear-mounted convex mirrors is one possible means of improving drivers' rear visibility to fill-in important portions of the blind zone. In order to further investigate the ability of supplemental rear-mounted convex mirrors to fill-in parts of the blind zone, NHTSA conducted research aimed at answering the following questions for each of a selection of commercially-available mirrors:

1. What additional area behind the vehicle does this supplemental mirror allow the driver to see? In other words, what is the FOV of this supplemental mirror?
2. What is the quality of the image seen in this supplemental mirror at each point in its FOV?
3. If this mirror is used optimally by drivers, what is their potential for reducing backover crash risk? In other words, how important is that portion of the blind zone filled-in by this mirror for preventing backover crashes.

Note that this study did not attempt to examine whether drivers will successfully use rear convex mirrors to successfully avoid hitting pedestrians. Additional human factors research would have to be performed to resolve this question. This question of potential overall effectiveness of rear-mounted convex mirrors, relative to other solutions to expand the driver's rear field of view, will be the subject of additional agency research.

REAR-MOUNTED CONVEX MIRRORS

Supplemental rear-mounted convex mirrors are commercially available, either as aftermarket equipment or original equipment (found on certain model years of Toyota 4Runner). These mirrors are of three basic types: single look-down mirrors, single corner mirrors, and paired cross-view mirrors.

Look-Down Mirrors

A look-down mirror is a single exterior convex mirror mounted behind the center of the vehicle near the top of the rear window. The mirror's convex surface points downward and is visible to the driver either by direct glance or in the interior rearview mirror. Look-down mirrors are sold as aftermarket accessories for vans and sport utility vehicles.

NHTSA tested one aftermarket look-down mirror during this research, a K Source C088, which was mounted on a 2007 Honda Odyssey. Figure 1 shows this mirror as tested.

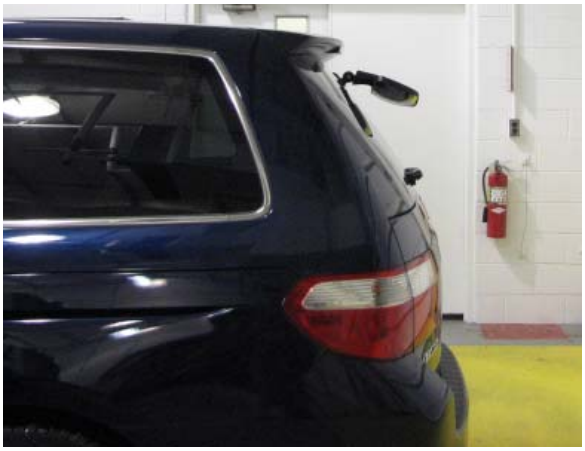


Figure 1: K Source C088 Look-Down Mirror Mounted on 2007 Honda Odyssey.

Corner Mirrors

A corner mirror is a single exterior convex mirror mounted on an arm projecting from the top, left, rear corner of the vehicle. The mirror's convex surface faces downward and is visible to the driver in the driver's side rearview mirror. Corner mirrors are aftermarket accessories most commonly used on delivery trucks and post office vehicles, but can be mounted on vans and sport utility vehicles.

In 2007, NHTSA measured the FOV and image quality for a Velvac™ RXV 254 mm-diameter convex mirror mounted as a corner mirror on a 1996 Grumman-Olson 4x2 Step Van. Results from the evaluation of this mirror are contained in a report by Mazzae and Garrott [2]. In the current effort, the previously collected data on the Velvac™ RXV rear corner mirror was used to estimate the field of view and image quality for this mirror as mounted on a 2008 Chevrolet Express van. Figure 2 is a picture of this rear corner mirror mounted on this vehicle. NHTSA did not retest the Velvac™ RXV rear corner mirror mounted on the 2008 Chevrolet Express but instead used linear extrapolation plus two dimensional interpolations to account for differences in vehicle size. Details of this extrapolation/interpolation process are provided below.

Figure 2: Velvac™ RXV Rear Corner Mirror Mounted on 2008 Chevrolet Express.

Rear Cross-View Mirrors

Rear cross-view mirrors consist of two mirrors mounted either inside or outside the vehicle in such a way that one mirror reflects an area to the left-rear of the vehicle while the other mirror reflects an area to the right-rear. Both mirrors (not necessarily at the same time) can be viewed by the driver either by direct glance or by looking in the interior rearview mirror. Rear cross-view mirrors are sold as aftermarket accessories for vans and sport utility vehicles, and can also be found as original equipment on some Toyota 4Runners.

NHTSA tested three (one original equipment and two aftermarket add-ons) pairs of rear cross-view mirrors during this research. The one original equipment pair, shown in Figure 3, consisted of two convex mirrors mounted on the C-pillars of a 2003 Toyota 4Runner.

Figure 3: 2003 Toyota 4Runner Rear Cross-View Mirror. [3]

The aftermarket rear cross-view mirrors tested were made by ScopeOut™. A pair of ScopeOut™ mirrors for cars was tested on a 2006 BMW 330i. This mirror pair is shown in Figure 4.

Figure 4: ScopeOut™ Passenger Car Rear Cross-View Mirrors Mounted on 2006 BMW 330i.

The other pair of aftermarket cross-view mirrors was the ScopeOut™ product designed for SUVs. These mirrors were tested mounted on a 2007 Honda Odyssey. This pair is shown in Figure 5.

Figure 5: ScopeOut™ SUV Rear Cross-View Mirrors Mounted on 2007 Honda Odyssey.

MIRROR ADJUSTMENT FOR TESTING

All mirrors were adjusted prior to making measurements to provide what the persons conducting the tests considered to be the most useful mirror orientation. Note that this is inherently a subjective process – different people may have differing ideas as to the most useful mirror orientation based on driver height, seating position, and other factors.

MIRROR FIELD OF VIEW MEASUREMENT METHODOLOGY

Measurements of mirror fields of view were made for the look-down mirror and the three pair of rear cross-view mirrors using the same methodology published by Mazzae and Garrott [4]. Fields of view were measured with each vehicle positioned on a flat test surface covered with a grid of 30 cm squares. The visual target was a 711 mm tall traffic cone with a 76 mm diameter red, circular reflector sitting atop it. The combined height of cone and reflector was 747 mm to simulate that of a standing 1-year-old child. This height was the average of the Center for Disease Control's growth chart values for the 50th percentile standing height for a 1-year-old boy and 1-year-old girl [5, 6]. The 76 mm diameter reflector was somewhat smaller than that of the average 1-year-old child's head (127 mm) [7].

Measurements were made with one person (the 'driver') in the driver's seat reporting whether or not they could see the reflector and a second person moving the visual target and manually recording whether or not the target could be seen at each location on the grid. The visual target was considered "visible" if the driver could see the entire reflector mounted atop the traffic cone.

One driver was used: a 50th percentile male (175.5 cm tall) [8]. The driver rested his weight fully on the driver's seat and positioned his feet as close as possible to where they would be during driving. The subject wore lap and shoulder restraints. The driver's seat and head restraint positions were adjusted to positions appropriate for his or her height. Head restraints for unoccupied seats were in their lowest possible (stowed) position. Any folding rear seats were in their upright (occupant-ready) positions. The vehicle's windows were clean and clear of obstructions (e.g., window stickers).

Once the vehicle and driver were properly positioned, the FOV assessment began. A member of the research staff placed the cone in a square and the driver reported whether or not they could see the reflector. The responses were recorded manually on a data sheet by the person outside the vehicle.

MIRROR IMAGE QUALITY MEASUREMENT METHODOLOGY

Measurements of the quality of images visible in the various rear mirrors were made for the look-down mirror and the three pair of rear cross-view mirrors using the same methodology as described in [2]. This methodology is based upon a methodology originally published by Satoh et al. in 1983 [9]. This methodology has been used for other NHTSA research that required the measurement of the quality of images seen in school bus cross-view mirrors and forms the basis for the school bus cross-view mirror test that is in S9 and S13 of FMVSS No. 111 (Garrott, Rockwell, and Kiger [10]).

There are two parts to the measurement of the quality of images visible in the various rear mirrors: (1) determination of the minification of test objects that are viewed in the various rear mirrors, and (2) quantification of the amount of image distortion. Minification is defined as how large objects appear when viewed in the mirrors. Distortion is defined as how apparent shapes of objects change when viewed in the mirrors.

Mirror image quality measurement was performed using a camera placed on a tripod in the vehicle at a selected driver eye position. The driver eye position selected was that of a 5th percentile adult female driver. This driver eye position was selected because it is the one used in FMVSS No. 111 for the school bus cross-view mirror compliance test. Note that for convex mirrors, mirror image quality is relatively insensitive to driver eye position **provided the driver can clearly see the mirrors**.

As specified in S13.4 of FMVSS No. 111 [11], the position of the image plane of the camera used to take the image quality determination photographs was determined by first adjusting the driver's seat of the test vehicle "to the midway point between the forward-most and rear-most positions, and if separately adjustable in the vertical direction, adjust to the lowest position." After making the necessary measurements, the seat was removed from the vehicle. The camera was mounted on a tripod with the center of the image plane laterally at the center of the seat, longitudinally at the intersection of the seat cushion and the seat back, and vertically 686 mm above the intersection of the seat cushion and the seat back.

Image Minification Determination

The driver's expected ability to see child-size objects in various rear convex mirrors was measured using both the Hybrid III 3-year-old (H-III3C) Anthropomorphic Test Device (ATD) and the Child Restraint/Air Bag Interaction (CRABI) 1-year-old ATD.

These ATD's were placed at a grid of test locations that covered each mirrors' FOV. The spacing between grid locations was generally 60 cm either laterally (across the width of the vehicle) or longitudinally (in the fore-and-aft direction). A 60 cm grid spacing was used to minimize the photograph analyzer's workload based on the belief that it was not important to know distortion ratings with a higher spatial granularity. Photographs were taken of each ATD at each test location. Figure 6 shows a typical photograph of the 3-year-old ATD positioned behind the vehicle.

At each grid location, the dummies were photographed by a camera mounted on a tripod in the previously described driver eye position. To make it easier to measure minification, these photographs were taken using an up to 8x optical zoom.

Figure 6: Typical Picture of 3-year-old ATD as Seen in 2003 Toyota 4Runner Rear Cross-View Mirror.

The visual angle at the driver's eyes that was subtended by both the 1- and the 3-year-old ATD's was determined at each test location. While in principle measurements of apparent ATD size and optics could have been determined this, due to fears that the optical zoom being used when the needed photographs were taken might not provide exactly the anticipated magnification, a "Sizing Object" was used.

The Sizing Object consisted of a 30 cm square piece of Styrofoam, the front of which was covered with orange construction paper. Centered in the 30 cm square was a 15 cm square piece of blue construction paper. The Sizing Object was placed immediately next to the mirror being tested, oriented so that the line of sight to the camera was perpendicular to the Sizing Object. Only a portion of the Sizing Object was generally visible in the photographs that were taken to determine the subtended visual angles.

To determine the subtended visual angle for each ATD at each grid location, the analyst first selected and measured the longest dimension of the ATD image. This length was called the Measured Length - Longest Direction and gives the best (easiest) case for the driver to see the ATD. All measurements were made to the nearest millimeter and had an estimated accuracy of ±0.5 mm. In the direction perpendicular to the longest dimension of the ATD image, the analyst then selected the point where the ATD image was the widest. The resulting length was called the Measured Length - Shortest Direction and gives the worst (hardest) case to see the ATD.

The known dimensions of the portion of the Sizing Object visible in each photograph were used to calculate true values of each Measured Length - Longest Direction and Measured Length - Shortest Direction.

The following equation, obtained from geometric optics, was used to calculate the subtended visual angles:

$$\theta = 60 \sin^{-1}\left(\frac{d}{(a+b)}\right)$$

where:

- θ is subtended visual angle in minutes of arc.
- a is the measured distance from the driver's eyepoint to the center of the rearview (either center mirror or driver's sideview mirror) mirror.
- b is the measured distance from the center of the rearview mirror to the surface of the rear convex mirror.
- d is the measured ATD dimension. This will be either Measured Length - Longest Direction or Measured Length - Shortest Direction.

and $\sin^{-1}$ is calculated in units of degrees.

Table 1: Relationship Between Subtended Visual Angle, θ, and Subjective Degree of Image Visibility

Level	Degree of Image Form	Degree of Image Size	Visual Angle (minutes)
5	Excellent	No Image Small	>50
4	Good	Small, but no Problem	20-50
3	Fair	Small, but Possible to Judge	10-20
2	Poor	Small and Hinders Judgment	5-10
1	Very Poor	Impossible to Judge	3-5
0	Impossible	Impossible	<3

Once the subtended visual angle had been determined for each grid location, Table 1 was used to determine a subjective degree of image visibility at each test location. Note that Table 1 is taken from Satoh [9] except for the lowest line. The final line was added by the authors so as to allow a subjective rating to be assigned at test locations for which the subtended visual angle was less than 3 minutes of arc.

IMAGE DISTORTION

The rear-mounted convex mirrors tested in this study are fairly mild convex mirrors with fairly large radii of curvature. As a result, image minification, **not** image distortion tends to be the limiting factor for what drivers can see in these mirrors. Therefore, for the sake of brevity, the image distortion methodology used and the results of the image distortion measurements results will not be presented in this paper.

REAR CORNER MIRROR EXTRAPOLATION/ INTERPOLATION METHODOLOGY

As mentioned above, NHTSA did not retest the Velvac™ RXV 254 mm-diameter rear corner mirror mounted on different vehicles but instead used the data that NHTSA had previously collected [2] with linear extrapolation plus two dimensional interpolation to account for differences in vehicle size.

The measured minutes of arc subtended by the test object were first linearly extrapolated to estimate the effects of differences in the driver eyepoint to side rearview mirror distance and side rearview mirror to rear corner mirror distance. Linear extrapolation is believed to provide a correct result because the image minification measurements were made after the surface of the rear convex mirror, after the non-linearities due to the curved mirror shape had already been introduced. Linear extrapolation is appropriate both before and after a flat mirror but not when a curved mirror lies between the driver and the measuring point. Note that the two distances involved were added together so only one extrapolation had to be performed.

Linear interpolation (linear extrapolation at the edge of the measured data) was then used to reduce vehicle track width from the 7.0 feet for the step van to the 6.0 feet more typical of light passenger vehicles.

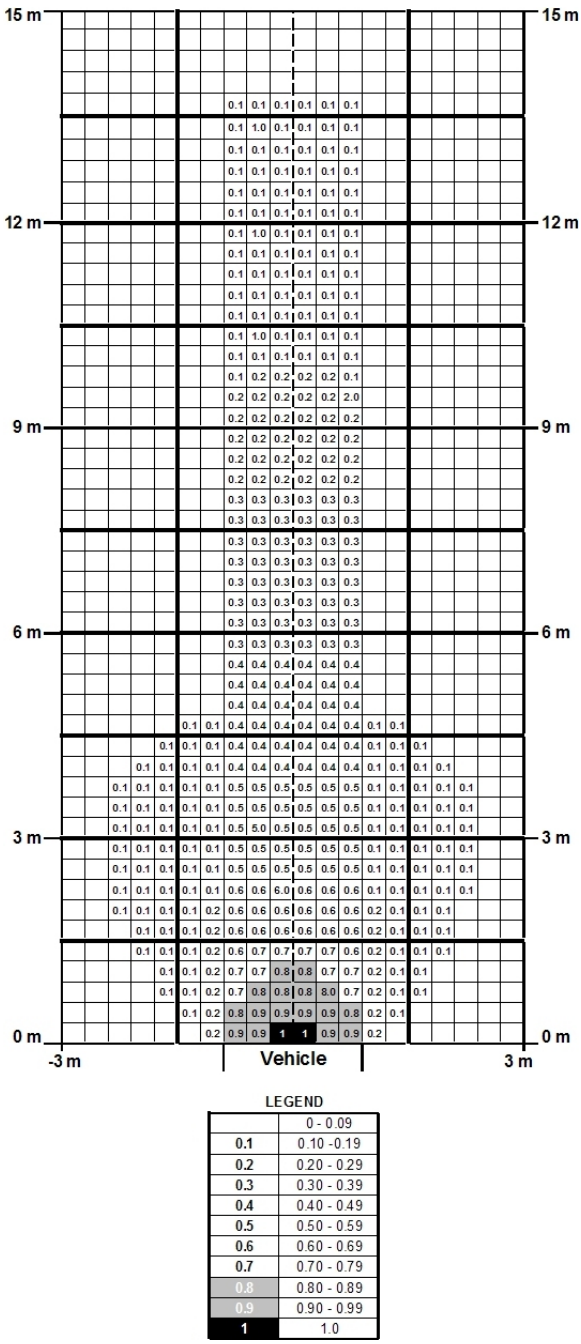
RELATIONSHIP BETWEEN PEDESTRIAN LOCATION AND BACKOVER RISK

To better understand the importance of rear-mounted convex mirror fields of view providing the driver with visibility of specific areas behind the vehicle, Monte Carlo simulation was used to estimate the risk to a pedestrian at a specific location at the start of a backing maneuver. Equating the Monte Carlo simulation results with pedestrian backover risk as has been done for this paper depends upon one key simplifying assumption: **that the driver only looks at the rear-mounted convex mirror one time, prior to the start of the backing maneuver**.

There is some validity to this assumption. Looking at convex mirrors typically takes drivers longer and requires more concentration than to look at a flat mirror. Therefore, drivers are more likely to do so initially rather than while in the midst of backing (a time with relatively high driver workload).

However, some percentage of drivers will certainly look at a convex mirror during backing. NHTSA currently does not have any data on how drivers use convex mirrors during backing.

As mentioned above, Monte Carlo simulation was used to calculate a probability-based risk weighting for each square in a grid of 30-cm squares behind the vehicle. Details of this Monte Carlo simulation are discussed in the Advanced Notice of Proposed Rulemaking (ANPRM) for Federal Motor Vehicle Safety Standard No. 111 on Rearview Mirrors [12]. Figure



7 (which is copied from the ANPRM except that the distance dimensions have been changed to metric units) shows the estimated backover risk for each location.

Figure 7: Summary of Simulated Relative Backover Crash Risk as a Function of Position

REAR-MOUNTED CONVEX MIRROR FIELDS OR VIEW

Figure 8 shows the measured FOV for the K Source C088 look-down mirror mounted on a 2007 Honda Odyssey minivan. As this figure shows, the look-down mirror FOV covers the entire width behind the vehicle beginning at 0.6 meters and extending to 3.9 meters behind the back of the rear bumper. In the zones 0.0 to 0.6 meters and 3.9 to 4.5 meters behind the rear bumper, some portions of the area behind the vehicle are in the FOV of this mirror.

Figure 9 shows the measured FOV for the Toyota 4Runner original-equipment cross-view mirror. As this figure shows, this mirror's FOV covers large areas to the left- and right-rear of the vehicle. However, there is an area of non-coverage near the center of the vehicle. Mirror coverage begins as close as 0.3 m behind the left side of the rear bumper. It begins further back on the right side, starting 1.2 m behind the right rear bumper.

Figure 10 shows the measured FOV for the Scope-Out™ car cross-view mirror pair mounted on a 2006 BMW 330i passenger car. As this figure shows, this FOV covers areas fairly far out on the sides of the vehicle on the left- and right-rear of the vehicle. There is a large area of blind area directly behind, and extending on both sides of the vehicle. Mirror coverage begins 4.5 m to the left of vehicle center and, on the left, 0.6 m behind the rear bumper. It begins 3.6 m to the right of vehicle center and, on the right, 0.9 m behind the rear bumper. This mirror pair is intended to allow the driver to see a vehicle coming towards him along the aisle of a parking lot; it may be effective for that application. For backover prevention, it suffers from having a vertical cut-off due to the height of the BMW 330i's rear window. This mirror should have a substantially larger FOV for children larger than a typical 1 year old child.

Figure 11 shows the measured FOV for the Scope-Out™ SUV cross-view mirror pair mounted on a 2007 Honda Odyssey minivan. As this figure shows, this mirror's FOV covers areas on the left- and right-rear of the vehicle. There is a moderate area of non-coverage directly behind the vehicle. Mirror coverage begins 0.3 m to the left of vehicle center and, on the left, 0.9 m behind the rear bumper. It begins 0.3 m to the right of vehicle center and, on the right, 0.3 m behind the rear bumper. Again, this mirror is intended to allow the driver to see a vehicle coming towards him along the aisle of a parking lot and it may be effective for that application.

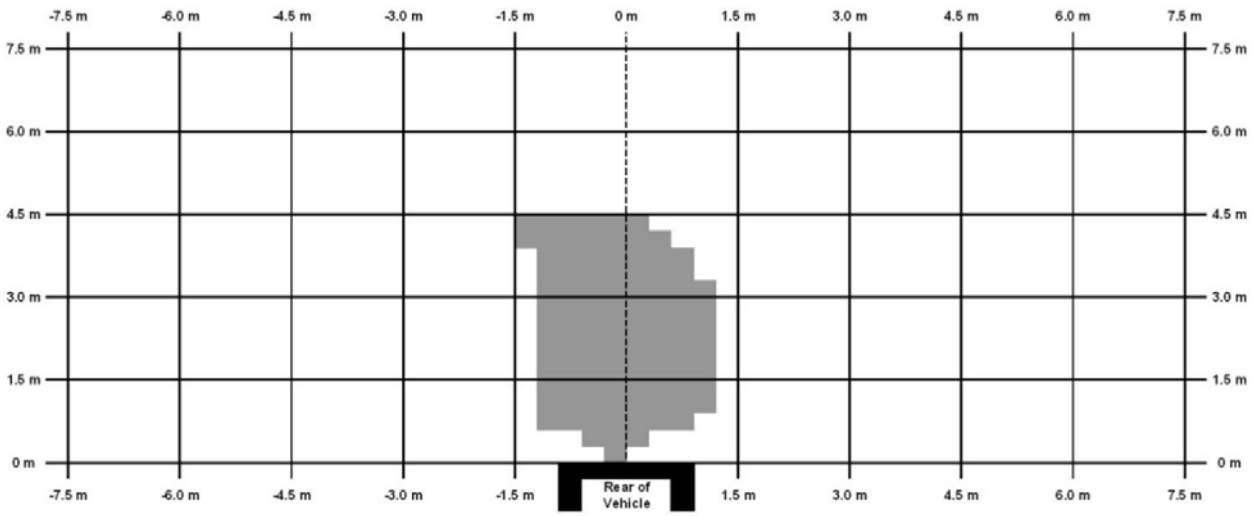


Figure 8. FOV for K Source C088 Look-Down Mirror Mounted on a 2007 Honda Odyssey

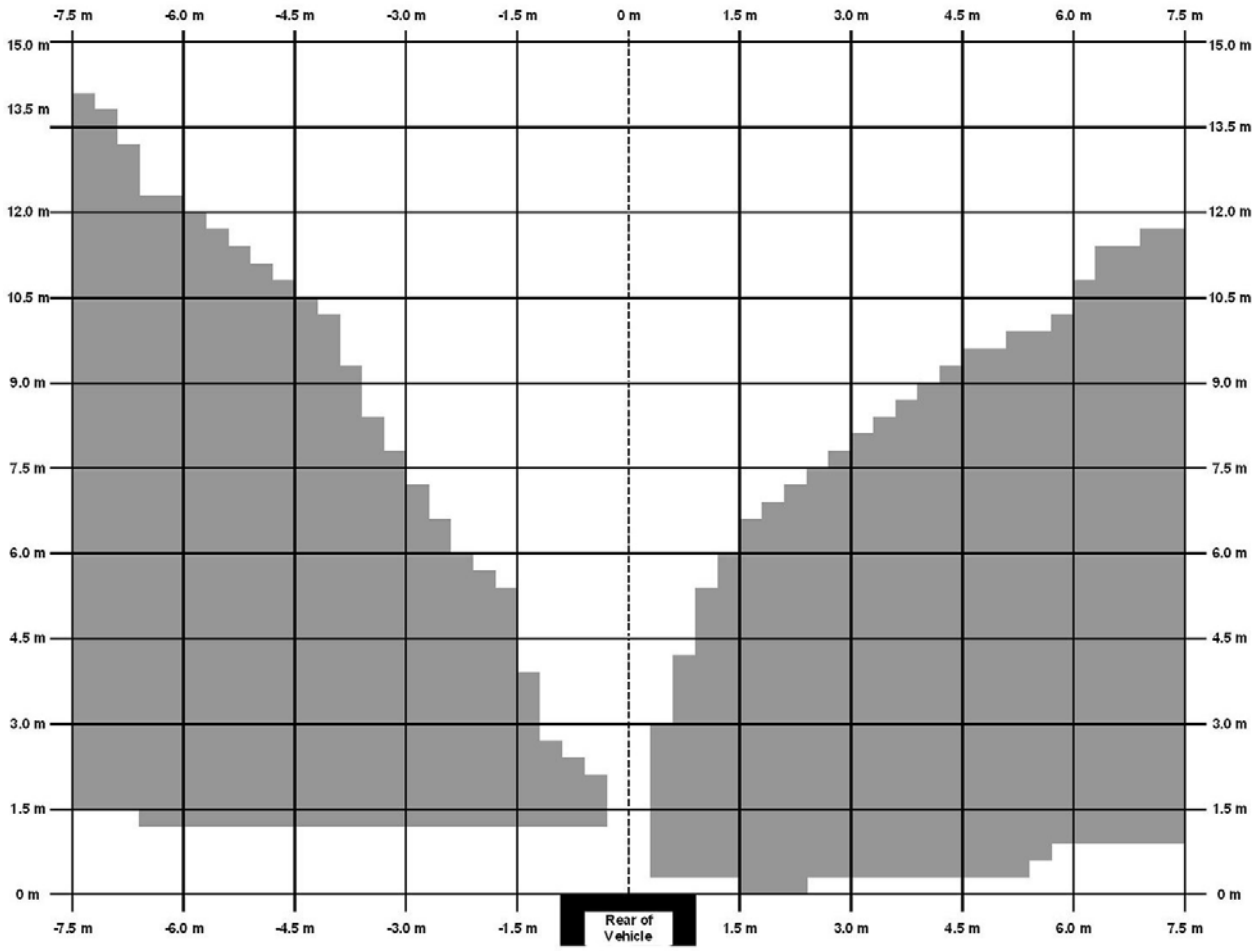


Figure 9. FOV for Original Equipment Rear Cross-View Mirrors on a Toyota 4Runner

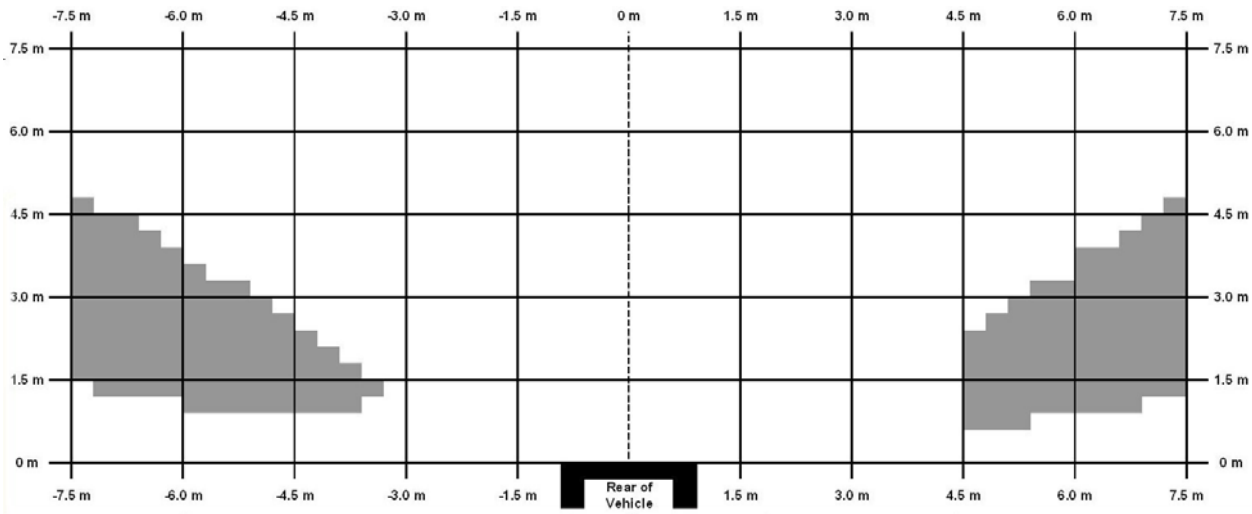


Figure 10. FOV for ScopeOut Aftermarket Equipment Passenger Car Rear Cross-View Mirrors on a 2006 BMW330i

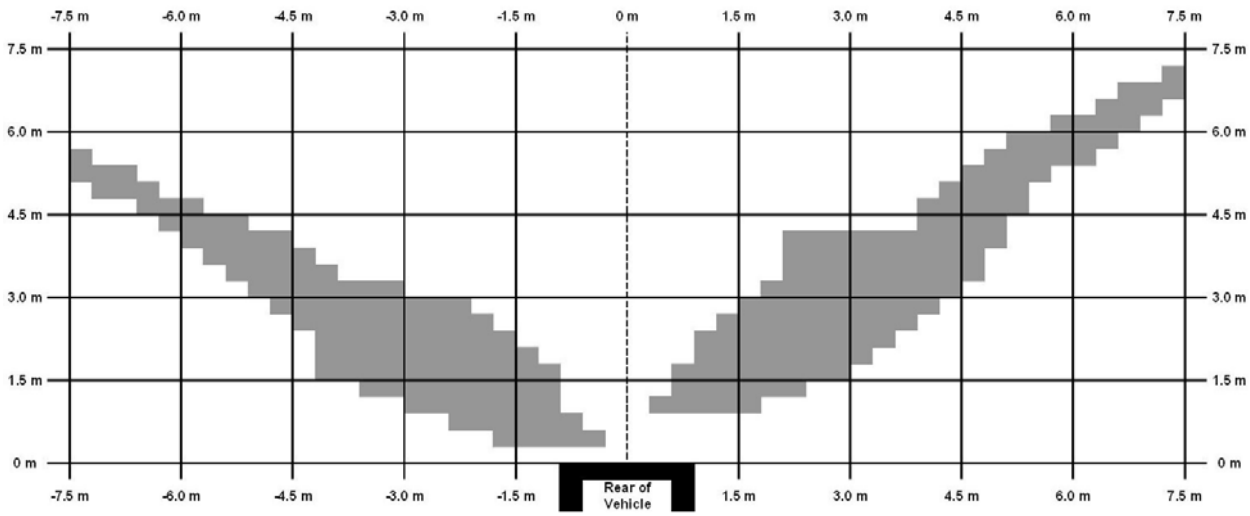


Figure 11. FOV for ScopeOut Aftermarket Equipment SUV Rear Cross-View Mirrors on a 2007 Honda Odyssey

The calculated FOV for the rear-mounted corner mirror mounted on a 2008 Chevrolet Express covers the entire area directly behind the vehicle plus a considerable distance on the left and right sides of the vehicle back for a distance of approximately 3.9 m. Note that image minification became so great near the edges of the mirror's FOV that it was impossible to precisely map the edges of this mirrors FOV. As is explained below, this mirror had a much smaller useful FOV.

ESTIMATED EFFECT OF THE LOOK-DOWN MIRROR ON BACKOVER RISK

The portion of the backover crash risk graph (shown in Figure 7) that lies within the measured FOV for the K Source C088 look-down mirror mounted on a 2007 Honda Odyssey minivan (shown in Figure 8) was calculated. This calculation found that, **if the driver could use the entire measured FOV of the K Source mirror, and the assumption that the driver only looks at the rear-mounted convex mirror one time, prior to the start of the backing maneuver holds,** this mirror has the potential to see the area associated with 20.8 percent of backover risk (as estimated using Monte Carlo simulation). This potential number may change based on the human factors aspects of how drivers use the mirrors.

Unfortunately, there is a large amount of image minification near the edges of the measured FOV of this mirror. There is also substantial image distortion, but not so much that drivers are thought not to be able to detect people behind their vehicle solely due to image distortion. Therefore, an image quality graph was developed for the K Source C088 look-down mirror

mounted on a 2007 Honda Odyssey minivan based solely on image minification. This graph is shown in Figure 12 and the key to this graph in Figure 13.

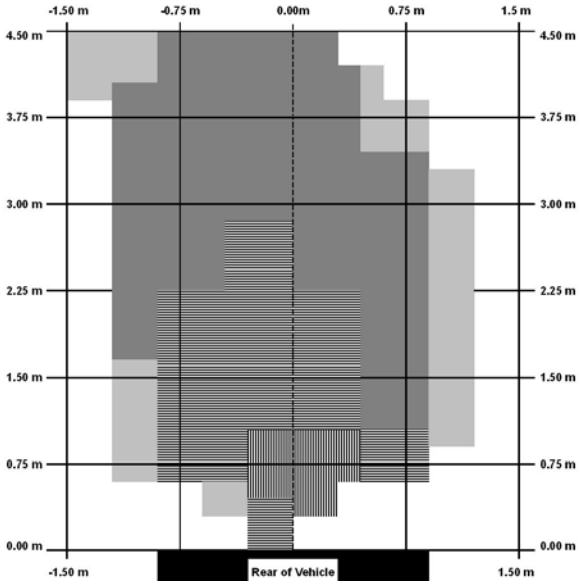


Figure 12: Image Quality Graph for K Source C088 Look-Down Mirror on 2007 Honda Odyssey

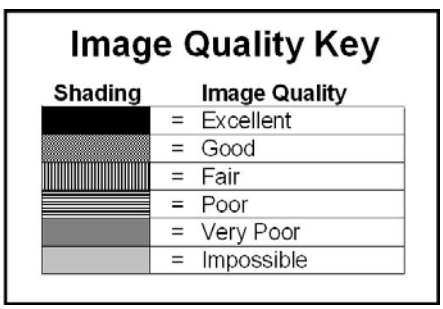


Figure 13: Image Quality Key used for Figures 12 and 14

As Figure 12 shows, the image quality, based solely on image minification, for the K Source C088 look-down mirror varies from "fair" to "impossible." As expected, the areas with the better image qualities are concentrated in the center of the vehicle fairly close to the vehicle's rear bumper.

Areas around the edges of the K Source look-down mirror's FOV have a minification rating of "impossible." In these areas, the driver has no chance of seeing a 1-year-old child. (The driver's chances of seeing someone in these areas improves as the person become larger.) These areas of "impossible" image quality reduce the "useful" FOV of this mirror.

Overlaying the areas of Figure 12 with a better than "impossible" image quality rating onto the backover crash risk graph (Figure 7) indicates that this area is associated with a backover risk (as estimated using Monte Carlo simulation) of 18.8 percent,, a small reduction from the all image qualities K-Source estimate of 20.8 percent.

As Figure 12 shows, there are substantial areas of the K Source look-down mirror's FOV (everything more than 2.85 m behind the vehicle's rear bumper) that have a minification rating of "very poor" or "impossible." The sides of the FOV forward of this location also generally have these image qualities. It is not clear whether a rapid glance by the driver prior to backing would really allow the driver to detect a 1-year-old child if that child were in an area of "very poor" image quality. Therefore, the backover risk reduction calculation for the K Source look-down mirror was also performed excluding all of the "very poor" image quality regions of the FOV. This yielded an estimated potential backover risk reduction of just 10.1 percent, less than one-half the estimate using the full FOV of 20.8 percent.

ESTIMATED EFFECT OF THE REAR CROSS-VIEW MIRRORS ON BACKOVER RISK

The portion of the backover crash risk graph (shown in Figure 7) that lies within the measured FOV for the three rear cross-view mirrors examined (shown in Figure 9, 10, and 11) was calculated. Again, this calculation is based on the **driver using the entire measured FOV of the rear cross-view mirrors, and the assumption that the driver only looks at the rear-mounted convex mirror one time, prior to the start of the backing maneuver holds.** This calculation found that these mirrors have the potential to see the areas associated with the following percentages of backover risk (as estimated using Monte Carlo simulation):

- Toyota 4Runner Mirror – 33.4 percent
- ScopeOut™ Car Mirror – 2.2 percent
- ScopeOut™ LTV Mirror – 9.1 percent

Neither image minification nor image distortion appears to be substantial enough to cause problems for the driver for any of the rear cross-view mirrors studied. Therefore, the useful FOV's of these mirrors matches their measured FOV's.

ESTIMATED EFFECT OF THE REAR CORNER MIRROR ON BACKOVER RISK

As discussed in [2], too much image minification is a problem for the Velvac™ RXV 254 mm-diameter

convex rear corner mirror that was evaluated. Image distortion was not a problem. Therefore, an image quality graph was developed for the rear corner mirror mounted on a 2008 Chevrolet Express van based solely on image minification. This graph is shown in Figure 14.

As Figure 14 shows, the image quality, based solely on image minification, for the Velvac™ RXV rear corner mirror varies from "poor" to "impossible." As expected, the areas with the better image qualities are concentrated on the left side of the vehicle fairly close to the vehicle's rear bumper (i.e., fairly close to the physical location of the actual mirror). As the figure shows, the "useful" FOV for this mirror covers only about one-half the width of the vehicle.

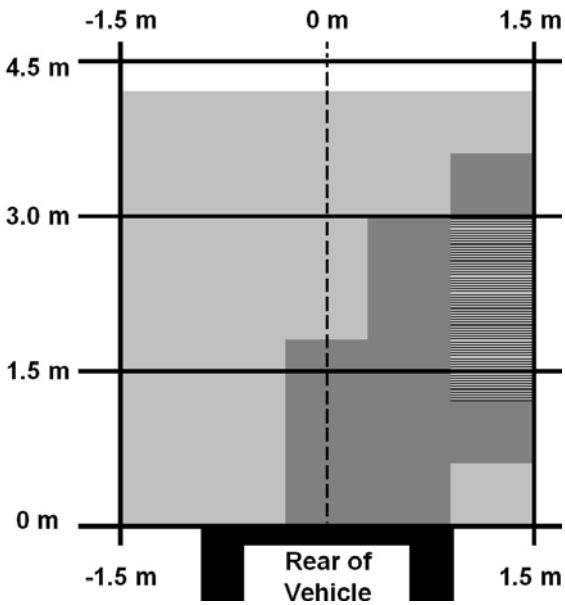


Figure 14: Image Quality Graph for Velvac™ RXV Rear Corner Mirror on the 2008 Chevrolet Express

As Figure 14 shows, there are large areas in the right portion and/or further away from the rear bumper of the Velvac™ RXV rear corner mirror's FOV that have a minification rating of "impossible." In these areas, the driver has little chance of seeing a 1-year-old child. (The driver's chances of seeing someone in these areas improves as the person become larger.) These areas of "impossible" image quality substantially reduce the "useful" FOV of this mirror.

Overlaying the areas of Figure 14 with a better than "impossible" rating onto the backover crash risk graph (shown in Figure 8) indicates a potential backover risk reduction for the Velvac™ RXV rear corner mirror of 10.8 percent.

As Figure 14 shows, almost all areas of the Velvac™ RXV rear corner mirror's FOV have a minification rating of "very poor" or "impossible." It is not clear whether a rapid glance by the driver prior to backing would really allow the driver to detect a 1-year-old child if that child were in an area of "very poor" image quality. Therefore, the backover risk reduction calculation Velvac™ RXV rear corner mirror was also performed excluding the entire "very poor" image quality regions of the FOV. This yielded an estimated potential backover risk reduction of just 0.9 percent.

CONCLUSIONS

In summary, the useful FOV's of five rear-mounted convex mirrors were determined. The potential backover risk reductions were estimated for the five mirrors studied, using only that portion of their FOV's with an image quality rating of better than "impossible." While data describing drivers' ability to use the mirrors effectively is a critical part of effectiveness estimation, that aspect is not addressed here. The estimated effectiveness of the technology itself ranged from 33.4 percent (for the Toyota 4Runner rear cross-view mirror) to 2.2 percent (for the ScopeOut™ passenger car rear cross-view mirror).

NHTSA currently has no data as to how drivers may use rear-mounted convex mirrors immediately before, and while, backing. Therefore, at this time, actual expected backover risk reductions due to rear-mounted convex mirrors are not determinable.

REFERENCES

[1] "Fatalities and Injuries in Motor Vehicle Backing Crashes," NHTSA Report to Congress (September 2008).

[2] Mazzae, E. N., and Garrott, W. R., "Experimental Evaluation of the Performance of Available Backover Prevention Technologies for Medium Straight Trucks," DOT HS 810 865, November 2007.

[3] Toyota Motor Company. Picture accessed 20 January 2009 from http://www.toyota.com/4runner/photo-gallery.html.

[4] Mazzae, E. N., and Garrott, W. R., "Light Vehicle Rear Visibility Assessment," DOT HS 810 909, September 2008.

[5] Center for Disease Control. "Clinical Growth Charts. Birth to 36 months: Boys; Length-for-age and Weight-for-age percentiles," May 30, 2000 (modified April 20, 2001).

[6] Center for Disease Control. "Clinical Growth Charts. Birth to 36 months: Girls; Length-for-age and Weight-for-age percentiles," May 30, 2000 (modified April 20, 2001).

[7] Henry Dreyfuss Associates, "The Measure of Man and Woman; Human Factors in Design (rev.)," John Wiley and Sons, New York, 2002.

[8] Grandjean, E., " Fitting the Task to the Man," Taylor and Francis, London, 1988.

[9] Satoh, H., Yamanaka, A., Kondoh, T., Yamashita, M., Matsuzaki, M., and Akisuzuki, K., "Development of a Periscope Mirror System," JSAE Review, November 1983.

[10] Garrott, W.R., Rockwell, T.H., and Kiger, S.M., "Ergonomic Research on School Bus Cross View Mirror Systems," NHTSA Technical Report DOT HS 807 676, August 1990.

[11] Code of Federal Regulations, 49 CFR Ch. V, §571.111 (10-1-06 Edition).

[12] Advanced Notice of Proposed Rulemaking, Federal Motor Vehicle Safety Standard; Rear-view Mirrors, Federal Register Vol. 74, No 41, P 9478-9420, March 4, 2009.

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