Preliminary Results of Joint ARB/DOSH/OSHSB Field Study of Retrofit Feasibility for Most Common Vehicles

Summary

Of the off-road vehicle types included in the study, which are the 50 most common types in the State, about 67 percent can be retrofit without visibility impairment, 30 percent can be retrofit with some visibility impairment, and for 3 percent of the vehicles, there is not currently a retrofit option available.

Background

In response to Petition 507 and the need to clarify the safety standards for exhaust retrofits, and at the request of the Governor's Office, Air Resources Board (ARB), Occupational Safety and Health Standards Board (OSHSB) and Division of Occupational Safety and Health (DOSH) staff have conducted a field study to examine the visibility impairment created by exhaust retrofits for 50 of the most common off-road diesel vehicle types. The study was conducted with the assistance the Operating Engineers Union, Associated General Contractors (AGC), Manufacturers of Emissions Control Association (MECA), California Department of Transportation, and manufacturers of off-road equipment and retrofit devices including Caterpillar, Cleaire, HUSS, DCL, ECS, Donaldson, and ThermaCat. Specifically, the objective of the field study was to determine the minimum masking (where 'masking' means the area where a vehicle operator's vision would be blocked by the retrofit) that would be associated with applying verified exhaust retrofits to each of the 50 vehicle types.[1]

As shown below, off-road equipment can be retrofit in various ways, some with no impairment of visibility (fig. 1) and some with a large impact on visibility (fig. 2).

Figure 1: Under-hood retrofit installation on a Caterpillar D5M.

Figure 2: Retrofit installation on the hood of a roller.

[1] This study only considered Level 3 retrofit devices currently verified by ARB (for more information on ARB's verification program and requirements, see http://www.arb.ca.gov/diesel/verdev/vt/cvt.htm). Devices that may be verified in the future, such as diesel particulate filters combined with selective catalytic reduction systems, were not considered.

Field Study Procedure

Test Method: To determine the minimum masking that would be associated with applying an exhaust retrofit to each of the 50 vehicle types, staff first had to develop a a repeatable, field-friendly test method. OSHSB and ARB staff began by analyzing the methods used in a number of visibility tests such as those outlined in SAE J1091 and ISO5006. These methods both rely on determining a standard height and placement for an operator's eyes when in the operator seat, and determining the obstruction from that point out to a set height and distance from the vehicle.

Similar to these methods, OSHSB and ARB staff jointly developed a more field-friendly method whereby:

- The operator eye-point is simulated by a test device sitting on the operator seat.
- The visibility impairment of a modification to the vehicle is measured from this eye-point to a railing placed around the vehicle.
- The distance on the railing that is blocked, from the line of sight of the operator, is considered the area masked from an exhaust retrofit component.
- The masking is measured first with the railing at 40 inches from the vehicle, and then moved outwards up to 40 feet.

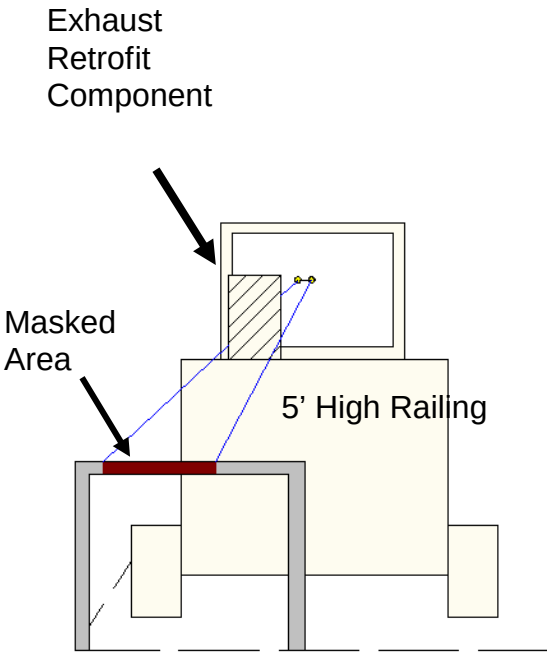


Figure 3: Visibility Test Method

The method is illustrated in fig. 3, where a retrofit exhaust cylinder is shown on a vehicle, and the masking created is shown on the railing placed behind the vehicle. The method is detailed in Attachment A.

Study Vehicles: To be as representative of all the off-road diesel vehicles used in California as possible within the allotted timeframe, staff considered the 50 most common vehicle models as reported to the Air Resources Board Diesel Off-road On-line Reporting System (DOORS). All off-road diesel vehicles were required by the off-road diesel vehicle regulation to be reported to this system by August 1, 2009. The full list of vehicle types is displayed in Table 2 on page 6.

These vehicles represent the five to eight most common models for the categories of graders, scrapers, loaders, excavators, backhoes, rollers, skid steers, forklifts, and crawler tractors. Where the top five models were are almost exactly the same, the first was selected but not the next few that were of the same design (i.e. the top 5 backhoe models were all variants of the Deere 210LE; the most common model was chosen and then the next model that was not a variant of the 210LE was selected).

Survey and Field Visits: Staff surveyed the manufacturers of verified off-road exhaust retrofits to determine how each vehicle model from the list would be retrofit - whether under-hood, by replacing the existing muffler, or by being placed on the vehicle body.

Where a vehicle could clearly be retrofit without an impairment to visibility (i.e. could not be done under-hood or by replacing existing components without increasing component size), there were no measurements to take in the field. The installations are, from the operator seat, out of sight.

For the vehicles where the installation was not out of sight, staff and representatives of equipment manufacturers (Caterpillar, Deere) and exhaust retrofit device manufacturers (Caterpillar, Cleaire, DCL, ECS, HUSS) visited the equipment in the field and measured the masking.[2]

Results of the Study

Table 1 below summarizes the results for vehicles in the study, based on whether they can be retrofit with no masking, some masking, or there are no exhaust retrofit devices for the vehicle at this time. Roughly two thirds of the vehicle types can be retrofit with zero masking, using the Joint OSHSB/ARB Visibility Study Test Method.

Table 1 - Portion of Vehicles that Can be Retrofit with No Masking, Using Joint OSHSB/ARB Visibility Study Test Method[3]

Can be retrofit with	Percent of vehicle types	Comments
Zero masking	67%	Loaders, backhoes, crawler tractors, skid steers, most excavators, some graders and scrapers.
Some masking	30%	Rollers, forklifts, some graders and scrapers.
Unknown (because no installer had interest in retrofitting)	3%	1 scraper and 1 crawler tractor, of 50 vehicles.

[2] The masking results summarized below include all responses received from exhaust retrofit device manufacturers; those providing responses included Caterpillar, DCL, ECS, and Huss.

[3] The results in Table 1 are based on consideration of Level 3 retrofit devices currently verified by ARB only. Table 1 is intended to summarize the visibility impact of retrofits on various vehicle types; it is not mean to not account for all engine-specific and duty-cycle specific variables, such as the fact that some engines do not attain sufficient exhaust temperatures to be retrofit with passive diesel particulate filters.

Masking Measured to Date

So far, among the 9 vehicles tested where the installation would cause masking, the masking ranges between 16 to 142 inches (406 to 1880 mm), with an average of about 60 inches. This suggests that, in general, retrofits can either be reasonably integrated into a vehicles structure such that they create little or no masking, or they cannot be and create a large amount of masking. As of May 10, 2010, for a few of the smaller rollers and forklifts where manufacturers indicated that a retrofit would cause masking, the field visits have not yet been completed; staff will update these results based on those field visits once available. The measurements from those additional site visits will not affect the results summarized in Table 1 above, but could affect the summary of masking measured to date in this section.

Table 2: Study Results for the 50 Most Commonly Reported Vehicles

Where the table indicates 'Yes' in the column "**Zero Masking Using Study Method?"** the vehicle can be retrofit and the retrofit would not create masking using the Field Study Procedure. The location of the device is noted in the right column.
"On Body" means the device was placed on top of the vehicle body, generally on the vehicle engine hood.
"Underhood" means the device was placed under the hood of the vehicle.
"Batt. Box" means the device would likely be placed in the battery box of the vehicle, and in most cases the exhaust would be routed up from the battery box to the original exhaust stack.
"Muffler replacement" means the device replaced the existing vehicle muffler.
"Unknown" means the model suitability for retrofitting, the resulting masking, and the location of the device if the vehicle was retrofit, are unknown.

Vehicle Type and Operating Mass, m, metric tons = 2200 lbs	**Manufacturer**	**Model**	**Engine Horsepower**	**Zero Masking Using Study Method**	**Location**
Wheel Loader					
m < 10	Deere	624J	165	Masking	On Body
	Caterpillar	930G	149	Yes	Underhood
10 < m < 25	Caterpillar	950G	196	Yes	Underhood
	Deere	644J	230	Yes	Underhood
	Caterpillar	966G	260	Yes	Underhood
25 < m	Caterpillar	980C	318	Yes	Underhood
	Caterpillar	988B	475	Yes	Underhood
Backhoe Loader					
	Deere	210LE	78	Yes	Batt. Box
	Caterpillar	420D	89	Yes	Batt. Box

	Deere	310G	77	Yes	Batt. Box
	Deere	410G	96	Yes	Underhood
	Case	580M	79	Yes	Underhood
Skid Steer	**Skid Steer Loaders**				
	Caterpillar	226B	57	Yes	Chassis Ext.
	Deere	317	57	Yes	Chassis Ext.
	Bobcat	S150	46	Yes	Chassis Ext.
	Bobcat	T190	66	Yes	Chassis Ext.
	Bobcat	S175	49	Yes	Chassis Ext.
Forklifts					
	Hyster	H155XL2	78	Masking	On Body
	Caterpillar	RC60	77	Masking	On Body
	Daewoo	D35S	80	Masking	On Body
	Caterpillar	TH460B	98	Yes	Muffler Replacement
	Sky Trak	8042	110	Yes	Muffler Replacement
Excavator					
m < 10	Bobcat	331	42	Yes	Chassis Ext.
	Bobcat	325	27	Yes	Chassis Ext.
10 < m < 25	Caterpillar	320C	138	Yes	Underhood
	Deere	200CLC	177	Masking	On Body
	Deere	225C	147	Masking	On Body

	Link Belt	240LX	162	Yes	On Body
25 < m	Caterpillar	330CL	247	Yes	Underhood
	Caterpillar	345Bl	345	Yes	Underhood
Rollers					
	Ingersoll-Rand	DD24	40	Masking	On Body
	Dynapac	CC122	30	Masking	On Body
	Caterpillar	CB-224E	33	Masking	On Body
	Caterpillar	CS-563E	150	Masking	On Body
	Hyster	C530A	76	Masking	On Body
Scrapers					
	Caterpillar	657E	605	Yes	Underhood
	Caterpillar	613C	175	Masking	Muffler Replacement
	Caterpillar	623B	365	Masking	On Body
	Terex	TS24B	450	Yes	On Body
	Deere	762	175	Unknown	Unknown
Graders					
	Caterpillar	140H	165	Yes	On Body
	Caterpillar	12G	145	Yes	Underhood
	Caterpillar	16H	265	Yes	Underhood
	Deere	772D	215	Masking	On Body
	Dresser	850	200	Masking	On Body
Crawler Tractor					
	Caterpillar	D8R	310	Yes	Underhood

	Caterpillar	D6H	165	Yes	Underhood
	Caterpillar	D10N	580	Yes	Underhood
	Deere	450G	79	Unknown	Unknown
	Deere	650J	95	Yes	Muffler Replacement

Table 3: Masking Measurements on Vehicles in the Field Study

Where the responses indicated that the installation would create masking, the following table demonstrates the masking measured. Where a vehicle is listed as "TBD", the masking has yet to be determined.

Type	Make	Model	Hp Reported to ARB	Summary	Masking Details
Wheel Loader	Deere	624J	129-205	16" Masking	Masking first visible 6' behind the vehicle. With 205mm eye spacing, masking is 16". With 405mm eye spacing, masking is 7". With 65mm eye spacing, masking is 23".
Forklifts	Hyster	H155XL2	50-105		TBD
Forklifts	Caterpillar	RC60	60-275	31" Masking	Masking first visible 40" from the vehicle. With 205mm eye spacing, masking increases to 31" with retrofit. OEM masking TBD (cannot be measured on a vehicle with a retrofit already installed).
Forklifts	Daewoo	D35S	70-92		TBD
Excavator	Deere	200CLC (200D LC tested)	460-483	140" Masking	Masking first visible 34 feet from operator to the right-rear quadrant. Masking taken at 40 foot circle. With 205mm eye spacing, masking is 140". Existing muffler compartment is 36" long and 11" wide. There is significant room underhood if the device manufacturer was interested in fabricating/designing an underhood solution.
Excavator	Deere	225C (LC tested)	147-148	182" Masking	Masking first visible ~35 feet from operator. Masking taken on 40 foot circle at 5 feet high. With 205mm eye spacing, masking is 182". Existing muffler is 28" by 12", underhood. There is significant room underhood if the device manufacturer was interested in fabricating/designing an underhood solution.
Rollers	Ingersoll-Rand	DD24	25-41		TBD

Rollers	Dynapac	CC122	25-31		TBD
Rollers	Caterpillar	CB-224E	30-46		TBD
Rollers	Caterpillar	CS-563E	150-173		TBD
Rollers	Hyster	C530A	50-100	34" Masking	Masking first visible at 40" in front of the vehicle. With 205mm eye spacing, masking is 34". With 405mm eye spacing, masking is 32".
Scrapers	Caterpillar	613C	125-220	17" Masking	Masking first visible 65" from the vehicle, to the right side of the operator. OEM masking is 6" with 205mm eye spacing. With 205mm eye spacing, masking is 17". With 65mm eye spacing, masking is 23".
Scrapers	Caterpillar	623B	150-365	52" Masking	Masking first visible 7' from the vehicle, to the right side of the operator. With 205mm eye spacing, masking is 52".
Graders	Deere	772D	185-230	87" Masking	Masking first visible 29' behind Operator Eye Point. With 205mm eye spacing, masking is 87". With 405mm eye spacing, masking is 74". With 65mm eye spacing, masking is 98".
Graders	Dresser	850	177-201	38" Masking	Masking first visible 23' behind Operator Eye Point. With 205mm eye spacing, masking is 38". With 405mm eye spacing, masking is 16". With 65mm eye spacing, masking is 56".

A. General.

This visibility test is an objective method for evaluating the effect of an exhaust system modification (retrofit) on operator visibility. The test uses a line of sight method to identify the area shielded (masked) from the operator's view by the vehicle's exhaust system equipment and measure the width of the masked areas (masking width) at a height of 5 feet (approximate upper chest height of the average male worker) above ground level.

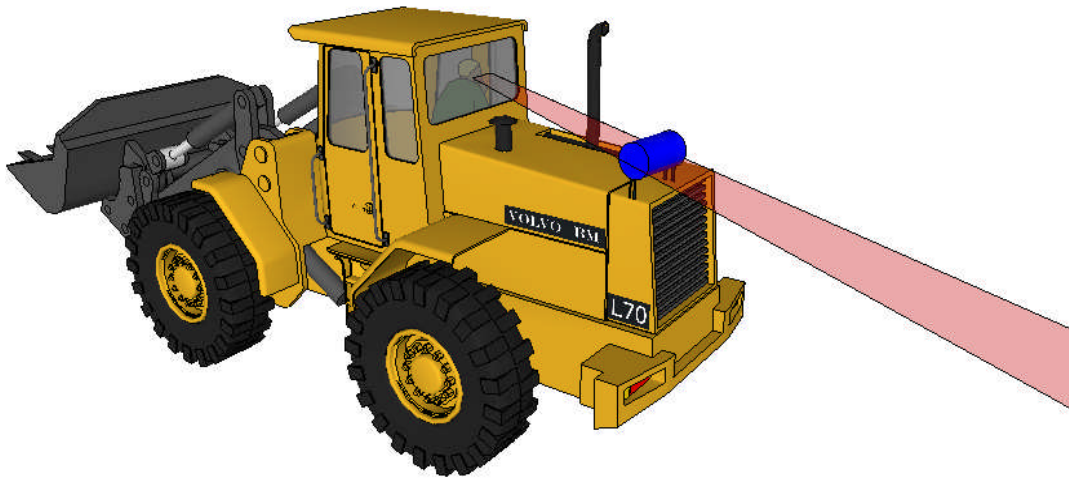
1. The visibility test must be performed under the supervision of a California Registered Professional Engineer.

2. A retrofit should not be installed where it would affect the structural integrity or safe handling (weight and balance) of the vehicle. A retrofit should not be located where the operator or workers would be exposed to heat from the retrofit that could result in an injury, or where a fire hazard would be created due to proximity to flammable or combustible materials.

3. A retrofit should, where practicable and safe, be installed in a location where it creates the least masking.

4. Where a retrofit is installed under the OEM hood without creating masking, it is not necessary to perform many of the steps in this visibility test. Refer to Section F before beginning the visibility test on these types of installations.

5. Masking explained. Masking is the area where the operator's vision is blocked. The masking created by a retrofit is defined as the area around a vehicle that an operator could see before the retrofit is installed, but cannot see after the retrofit is installed. In Figure 1 a retrofit (shown in blue) has been mounted on the rear of the loader, and the area of masking it would create for an operator sitting in the seat is shown in red. This is the area the operator can no longer see due to the retrofit.



B. Vehicle Position.

1. Park the vehicle on an area of compacted earth or paved surface with a gradient of no more than 3% in any direction. The area must be of sufficient size to ensure that the measurements required by this procedure are conducted on a flat horizontal plane.

2. Turn off the vehicle engine, set the parking brake, and block the tires. Position attachments such as buckets and blades as they would be when moving the equipment and block them in place.

Exception: The bucket or blade may be lowered to the ground rather than blocked in the traveling position, provided that this lowered position has no effect on the measurement of the exhaust system masking.

C. Seat Index Point (SIP). The seat index point is a reference point that is used to establish the average operator's eye position and line of sight, which in turn is used to identify the area masked from the operator's view.

1. If the seat pan has a tilt feature, adjust the seat pan so that it is as level as possible.

2. If the seat height can be adjusted, adjust the seat height so that it is midway between the maximum and minimum height.

3. If the seat can be adjusted forwards and rearwards, adjust the seat so that it is midway between the maximum forward and maximum rearward position.

4. If the compression of the seat pan is adjustable, adjust the compression as follows:

a. If the seat compression control is designed to be adjusted to the operator's weight, set it to approximately 190 lbs. (86 Kg.).

b. If the seat compression control does not have a setting for the operator's weight, adjust the compression such that it is midway between its maximum and minimum range.

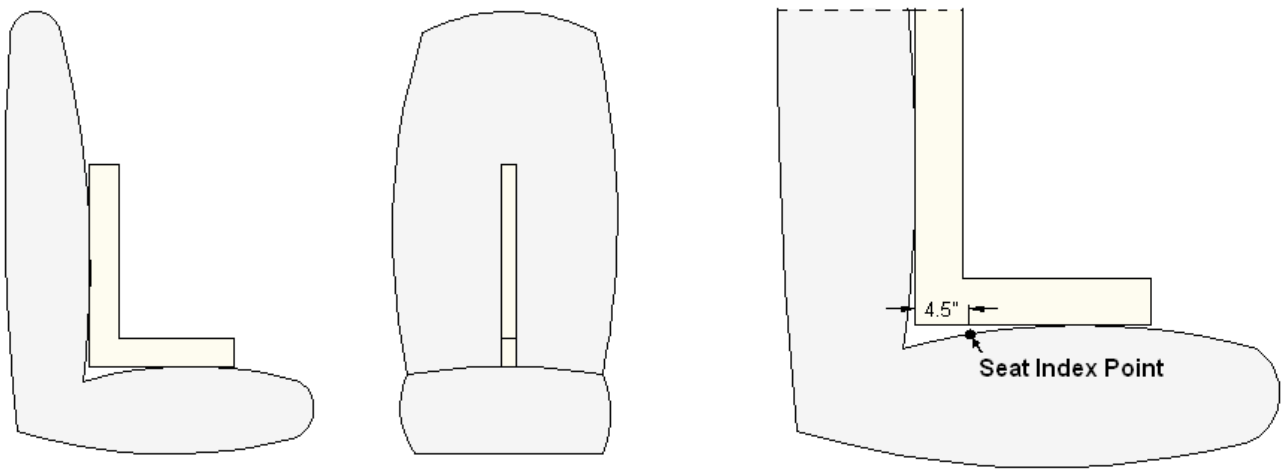
5. Locate the seat index point (SIP).

a. Place a carpenter's square on its edge on the seat cushion, as follows:

1) Rest the edge of one arm of the square on the seat cushion such that it is level and laterally centered on the seat (i.e. on the center line of the seat that extends from the front to the back).

2) Position the other arm of the square such that it is vertical and its edge touches the most forward part of the seat backrest.

b. Mark a point on the seat cushion that is directly below the bottom edge of the square (i.e. on the seat center line) and 4 ½ inches forward of the most forward part of the backrest. This point is the <u>seat index point (SIP)</u>.



D. Light Filament Height.

The light filament height (i.e. distance from the SIP to the vertical center of the light source) represents the eye level of the average operator. The operator's eye level is determined by the operator's seated height, the unloaded seat height, and by how much the seat compresses when the operator sits in it. Seat compression is measured and used to determine the light filament height, as follows.

1. Select a person weighing 165 to 215 pounds to be the test operator. Have the test operator sit on a hard bench or similar surface that does not compress under weight. Measure and record the distance from the seat surface to the top of the test operator's head.

2. Have the test operator sit upright in the operator's seat with the seat adjusted as described in Section C. Measure and record the distance from the top of the operator's head to a fixed reference point directly above. If the vehicle has a cab, the cab ceiling may be used as the fixed reference point. If the vehicle does not have a cab or a roll bar, a fixed reference point may need to be constructed (e.g. PVC pipe shaped and positioned like a roll bar).

3. For this step, the seat must be unoccupied and adjusted as in Section C. Measure the distance from the cab ceiling or fixed reference point used in step D-2 to the seat surface.

4. Calculate the seat compression as follows:

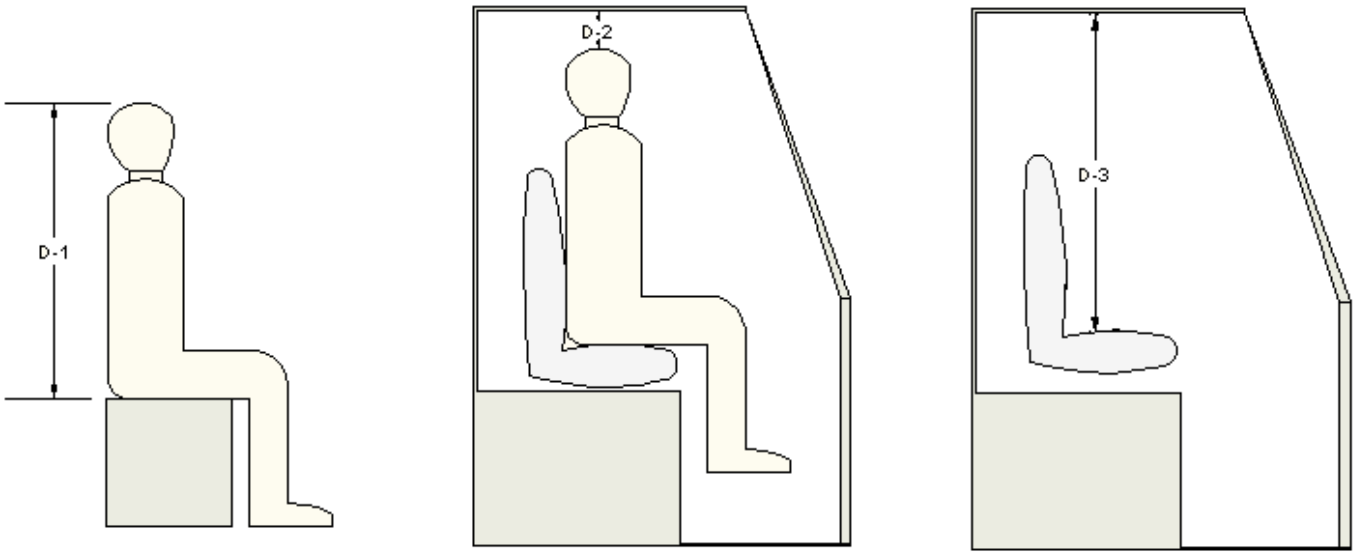
Seat compression = operator's seated height (D-1) plus distance from cab ceiling to top of operator's head (D-2) minus distance from cab ceiling to unloaded seat (D-3)

5. Calculate the light filament height as follows:

Light filament height = 30 ½ inches minus seat compression

6. Calculate the operator's eye level above ground as follows:

Operator's eye level = light filament height plus the distance from the SIP to the ground.



E. Light Source Position.

The position of the light bar and the 2 ½ inch spacing between the lights on the bar represent the position of the average operator's eyes when seated. Where the visibility test calls for a light spacing of 8 or16 inches, the light spacing is intended to account for the increased range of eye movement provided when the operator moves his or her torso and head.

1. Attach two lights to a bar (light bar) approximately 2 feet in length.

2. The position of each light on the light bar shall be adjustable such that the filament (i.e. center point) of the light source can be positioned from 1 ¼ inches to 4 inches on either side of the center of the light bar. The filament should be directly over the light bar or no more than 2 inches in front of the bar.

3. The lights must be of a type and intensity such that the center of the light filament can easily be identified in day light by a person standing 40 feet away.

4. The light bar must be capable of rotating 360 degrees on a horizontal plane with the axis of rotation centered between the two filaments. The light bar should be directly over the axis of rotation or no more than 1 inch in front of the axis of rotation.

5. Position the light bar such that:

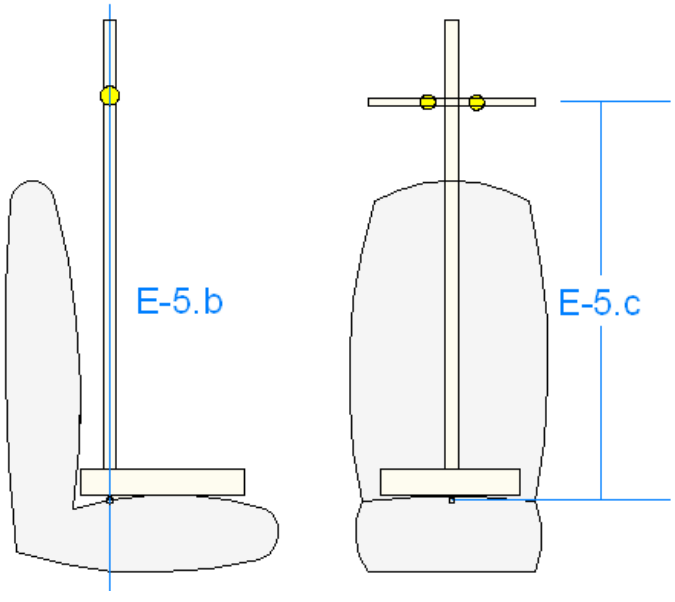
a. It is horizontal and rotates on a horizontal plane.

b. Its axis of rotation is directly above the seat index point.

c. The vertical distance between the seat index point and the vertical center of the light filaments is equal to the light filament height calculated in Step D-5.

6. When measuring masking, as instructed in the following Sections, rotate the light bar such that it is perpendicular to the line between it and the horizontal center of the object causing the masking.

7. A light bar device can be constructed and used to support the light bar in the correct position above the SIP. An example of such a device is shown below. A rod is mounted on a metal plate that sits in the operator seat and the device is adjusted so that the rod is vertical, the bar is the correct height, and the lights are rotated in the right direction.



F. Zero masking determination.

Retrofits do not increase masking if the filter canister does not obstruct the operator's view towards the ground in any direction and the masking created by the modified exhaust pipe(s) does not exceed that of the unmodified exhaust pipe(s). Both the filter canister and the exhaust pipe(s) must be considered when determining whether the retrofit creates masking, as follows.

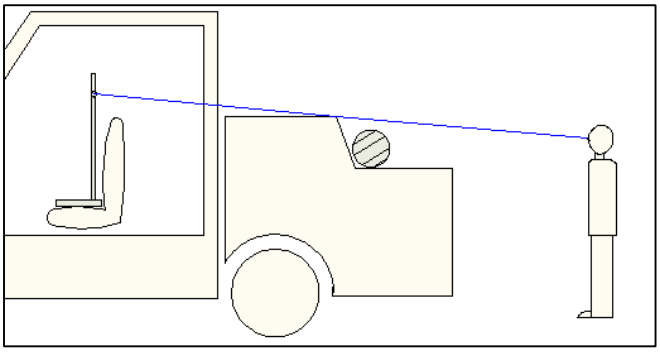
1. Filter canister. A canister does not create masking if the installation meets one of the following conditions.

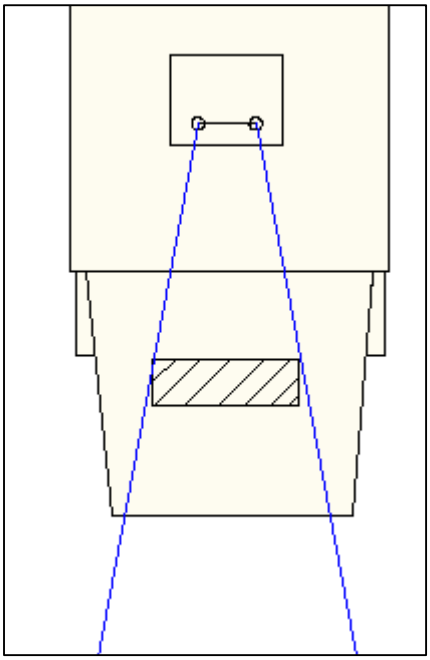
a. Installations under-hood. The entire canister is installed within the space of the vehicle's engine compartment without enlarging the hood of the engine compartment. If the hood is enlarged to accommodate the canister, the modified portion of the hood must be evaluated in accordance with step F-1b or F-1c to determine that the modification does not create masking.

b. Installations out of the operator's sight. The entire canister is shielded from the operator's sight by the OEM vehicle, as determined by the following steps.

1) Position the light bar as instructed in Section E with the light filaments equal distance from the center of the light bar and 2 ½ inches apart.

2) Stand behind the canister and look towards the lights. Adjust your eye position so that your line of sight is in line with the vertical center of the light and the edge of the vehicle above the filter. The canister does not create masking if no part of the canister blocks your view of the light as you move your line of sight (from the edge of the vehicle to the light) along the entire edge of the vehicle that is above the canister.

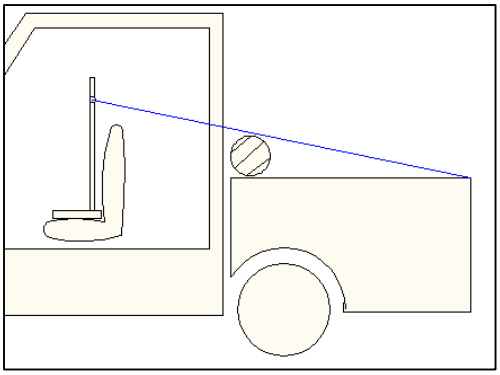


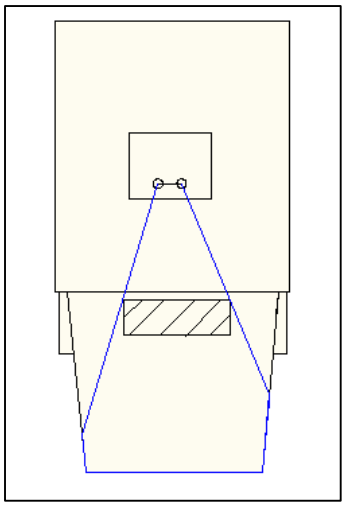


c. Installations below the operator's line of sight to the edge of the vehicle, as determined by the following steps.

1) Position the light bar as instructed in Section E with the light filaments equal distance from the center of the light bar and 2 ½ inches apart.

2) Stand behind the canister and look towards the lights. Adjust your eye position so that your line of sight is in line with the vertical center of the light and the edge of the vehicle that surrounds the filter. The canister does not create masking if no part of the canister blocks your view of the light as you move around the part of the vehicle that surrounds the canister and keep your line of sight in line with the edge of the vehicle and the light.





2. Exhaust pipe(s). The modified exhaust pipe does not create masking if all of the following conditions are met.

a) The modified exhaust it is not larger in diameter than the OEM exhaust pipe.

b) The modified exhaust is not closer to the operator than the OEM exhaust pipe

c) With respect to the operator's 360 degree view towards the horizon, the modified exhaust pipe is in the same position as the OEM exhaust pipe.

3. A retrofit does not increase masking if the exhaust pipe meets the conditions specified in step F-2 and the canister meets the conditions specified in step F-1a, F-1b, or F-1c. Where the retrofit does not increase masking in accordance with this Section, it is not necessary to complete Sections H and I, which measure masking.

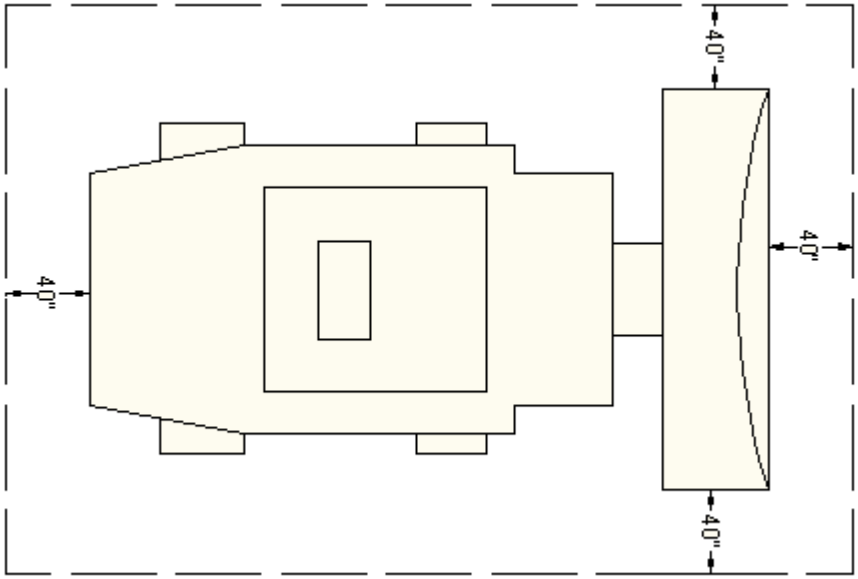
G. Masking at 40 inches from the vehicle.

The following steps measure the width of areas 5 feet above the test surface that are masked from the operator's view, at least in part, by a component of the vehicle's exhaust system. Perform the following steps with the OEM exhaust system on the vehicle, and repeat the steps with the modified exhaust system, or mockup, on the vehicle.

1. Position the light bar as instructed in Section E with the light filaments equal distance from the center of the light bar and 8 inches apart.

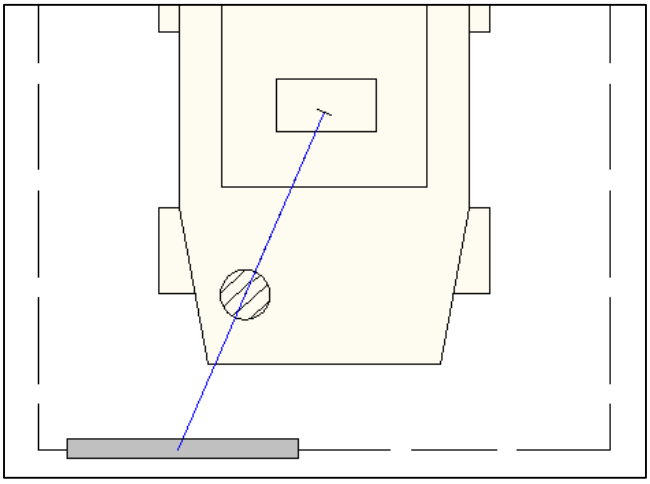
2. Mark a boundary line on the test surface at a distance of 40 inches from the smallest rectangle that can be placed around the vertical projection of the vehicle. For excavators, the front of the track shall be used for determining the boundary line. For other vehicles equipped with buckets or blades, the boundary line shall be determined

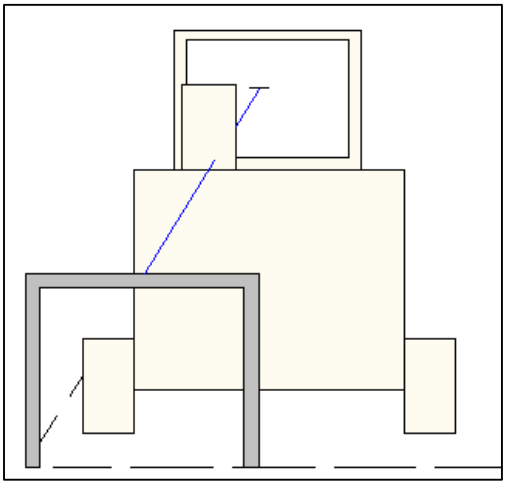
with the bucket or blade in the traveling position. It is not necessary to mark the boundary line around the entire vehicle, provided that the length and location of the marked area is sufficient to allow the measurements required in the following steps.



3. Use pipe or a similar straight, rigid material, to construct a horizontal railing that is 5 feet in height along its entire length. The railing must be self-supporting, stable, and of sufficient length to conduct the measurements required in this Section (a length of 5 to 10 feet is generally adequate).

4. Position the 5 foot high railing directly over the 40 inch rectangular boundary line such that, when standing behind the railing looking towards the light source, the approximate middle of the railing, middle of the exhaust component, and middle of the light sources appear to be on the same vertical plane.

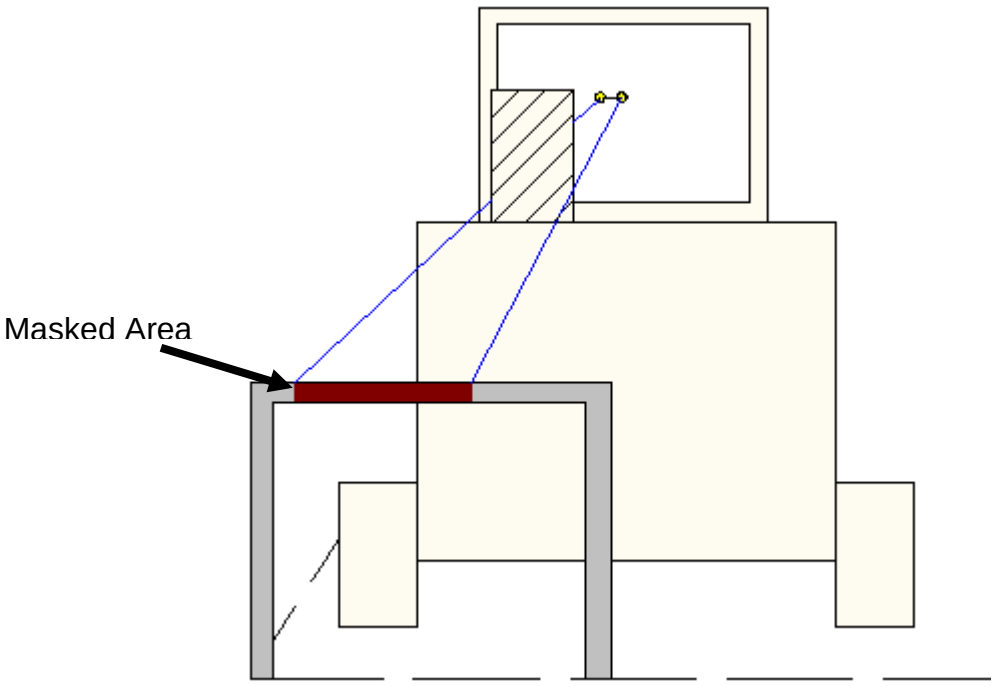




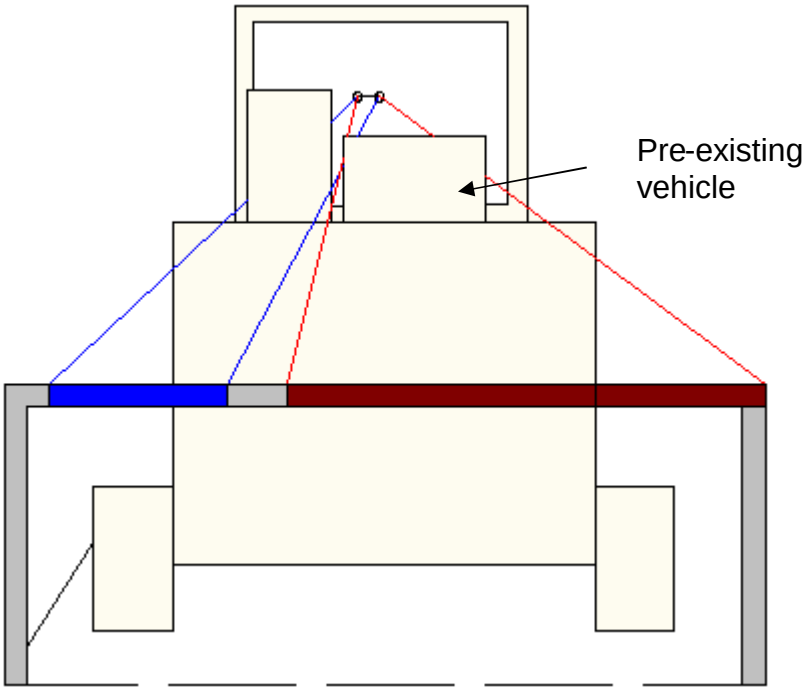
5. Stand behind the center of the railing, looking towards the light source, and position your eye height so that it is on the same horizontal plane as the top of the railing and the vertical center of the light source. Keep your eye at this height and

move along the length of the railing in both directions from one end of the exhaust component to the other. If, when following the instructions in the preceding sentence, the vertical center of the light source is not visible just above the top of the railing because the vehicle body, or a vehicle component other than an exhaust component, blocks the view of the light source (thereby preventing measurement of the exhaust masking width as instructed in this Section), skip to Section H. If all parts of the exhaust are below the line of sight from the top of the 5 foot high railing to the center of the lights, skip to Section J. If any part of the exhaust is visible on the line of sight from the top of the railing to the center of the light, continue with the next step.

6. Continue the process described in the preceding step. Find the point where one light source is totally blocked from view by the exhaust component and the other light source is at the transition point where half of the light source is in view and the other half is blocked by the obstruction. Mark this point on the railing using tape or similar means. This mark should be on the same vertical plane as the center of the light that is not totally blocked and the edge of the exhaust component creating the masking. This mark represents one side of the masked area. Move along the railing as before, find and mark the point on the railing that represents the other side of the masked area. This mark should be on the same vertical plane as the center of the light that is not totally blocked and the edge of the object creating the masking, which may be an exhaust component, a vehicle component, or the vehicle body. (When the area masked by an exhaust component overlaps with an area masked by the vehicle or another object, the width of the entire masked area is measured and considered to be the area masked by the exhaust component.) Measure the distance between the two marks on the railing that represent either side of the masked area and record this distance as the masking width of the exhaust component. When masking is continuous along two adjacent sides of the rectangular boundary, measure the masking along each side and combine the two measurements to determine the masking width.



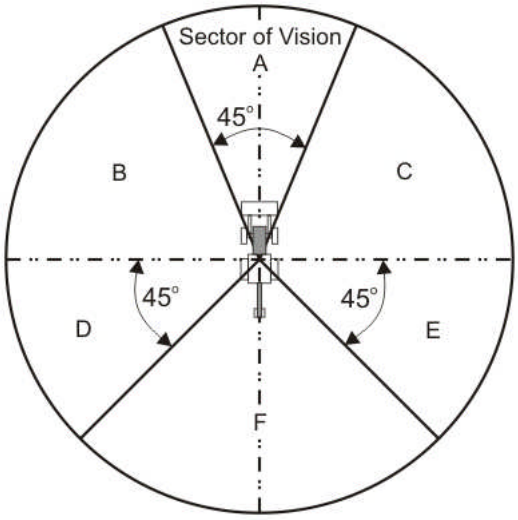
7. The space between the masking created by the exhaust component and an adjacent masked area can, if small, impair the operator's view or recognition of an object in that space. Therefore, it is necessary to measure and record the width of this space and the width of the adjacent masking, as follows. Start at the points marked on the railing in step G-6 that represent the sides of the area masked by the exhaust component. From these points, move along the railing, as instructed in step G-6, a distance of 12 inches. If an adjacent masking occurs within this distance mark the railing where the adjacent masking begins and ends. Measure and record the width of the adjacent masking and the width of the space between the masked areas. Where the adjacent masking width created by the vehicle body or another object exceeds 36 inches, the exact masking does not need to be measured provided that it is recorded as "Over 36 inches". If necessary, repeat this step until it is determined that there is no masking within 12 inches of an adjacent masking.



If the distance between the masking created by the exhaust component, shown in blue, is less than 12 inches from the masking created by existing vehicle components, shown in red, then take measurement of the adjacent masking as described in G-7.

H. Sector of vision.

Determine the sector of vision within which the majority of the masking lies, as indicated in the following diagram.



a) Sector of vision A is the segment of the visibility test surface encircling the vehicle that is to the front of the vehicle and encompasses an angle of 45 degrees and is bisected by the vertical plane passing through the SIP.

b) Sector of vision F is the segment of the visibility test surface encircling the vehicle that is to the rear of the vehicle and encompasses an angle of 90 degrees and is bisected by the vertical plane passing through the SIP.

c) Sector of vision D is the segment of the visibility test surface encircling the vehicle that is to the left-rear of the vehicle and encompasses an angle of 45 degrees forward of sector of vision F.

d) Sector of vision E is the segment of the visibility test surface encircling the vehicle that is to the right-rear of the vehicle and encompasses an angle of 45 degrees forward of sector of vision F.

e) Sector of vision B is the segment of the visibility test surface between sector of vision A and sector of vision D.

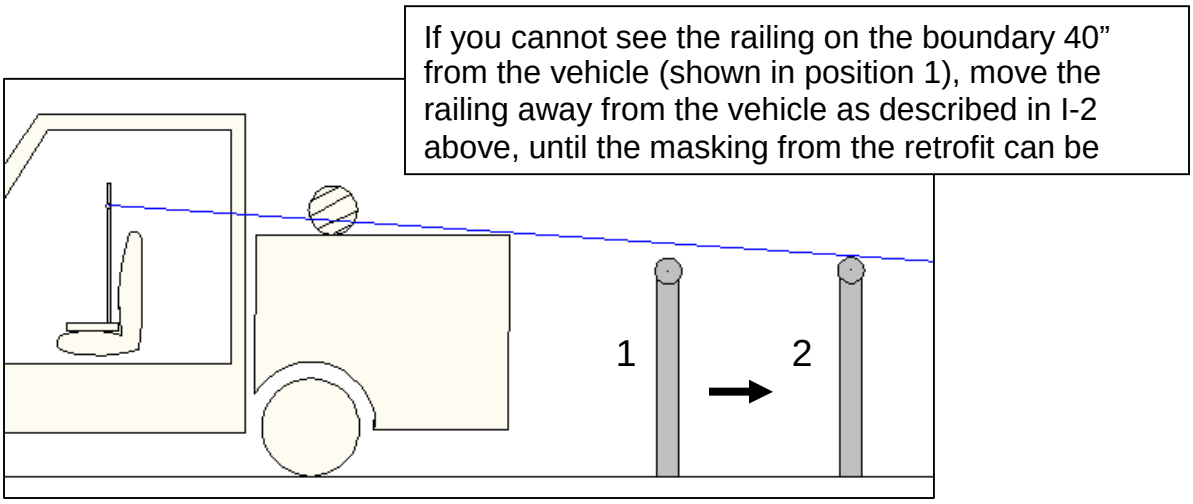
f) Sector of vision C is the segment of the visibility test surface between sector of vision A and sector of vision E.

I. Masking at up to 40 feet from the operator.

The following steps measure the width of the area 5 feet above the test surface that is masked from the operator's view, at least in part, by a component of the vehicle's exhaust system. Use the line-of-sight technique described in steps G-5 through G-7 to measure masking as instructed in the following steps. Perform the following steps with the OEM exhaust system on the vehicle, and repeat the steps with the modified exhaust, or mockup, on the vehicle.

1. Position the light bar as instructed in Section E. Perform steps E-2 through E-5 with the light filaments spaced 2 ½ inches apart and equal distance from the center of the light bar.. Repeat steps E-3 and E-5 with the lights spaced 4 inches apart.

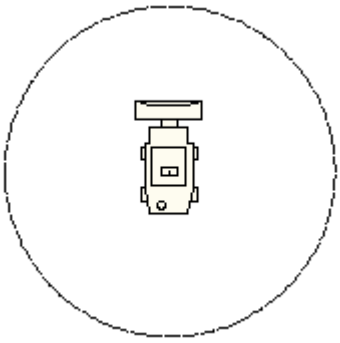
2. It is not necessary to complete this step if it was possible to measure the masking width at the 40 inch rectangular boundary as instructed in Section G. If, in step G-5, the vehicle body or vehicle component other than an exhaust component blocked the view of the light source and prevented measuring the masking width, complete this step. Move the 5 foot high railing away from the vehicle until a part of the exhaust just appears on the line of sight from the top of the railing to the vertical center of the light, or the railing is moved 40 feet away from the point on the ground directly below the SIP. If the vehicle body or vehicle component other than an exhaust component continues to block the view of the light source at a distance of 40 feet, skip this Section. At the point where masking from the exhaust first appears, measure the horizontal distance from the 5 meter railing to a point on the ground directly below the SIP. Record this distance as the masking radius. Where the vehicle tires or tracks prevent measuring the masking radius directly on the ground, measure or calculate the masking radius using an equivalent method.



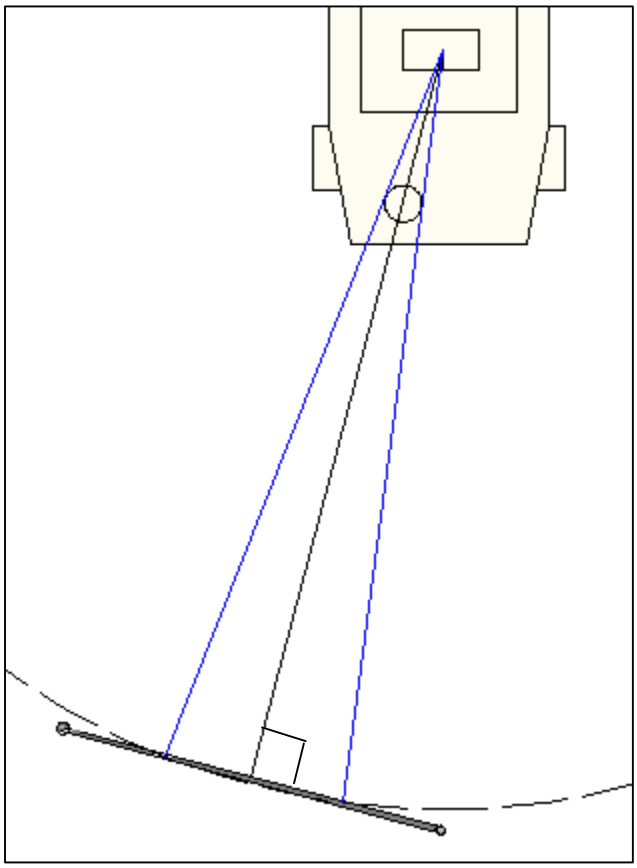
3. Measure the masking width of the exhaust at a masking radius of 40 feet. Position the railing so that it is perpendicular to the line of sight to the light source. To ensure that the railing is perpendicular and the masking radius is 40 feet, measure the masking radius from each of the two points on the ground that are directly below the marks on the railing which represent the masking width.

4. If there is no masking at a masking radius of 40 feet, determine the masking radius where the masking width narrows to zero.

5. If masking was measured at a masking radius of 40 feet, determine whether the masking is wider at a masking radius less than 40 feet. Measure the masking width and the masking radius at the distance from the SIP where the masking width appears to be widest.



This circle, 40 feet from the operator eye-point, defines the distance at which to measure the masking. Note that the railing is position so that it is perpendicular to the line of sight to the vehicle, and the edges of the masked area are measured at 40 feet, not the edges or center of the railing.



J. Test Report.

The test report shall include the following information:

1. Type of vehicle, manufacturer, and model number.
2. Tare (empty) weight.
3. Vehicle identification number.
4. Operator enclosure and/or protective structure description.
5. Equipment installed on the vehicle.
6. Other information that affects the visibility measurements.
7. Pictures or illustrations of the vehicle and exhaust configuration for the visibility test.
8. Manufacturer, model, and dimensions of the exhaust retrofit.
9. All measurements required in this visibility test.
10. Printed name, signature and contact information of person conducting the test.
11. Test date.