

Heavy-Duty Vehicle Rear-View Camera Systems

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ABSTRACT

Transport Canada, through its ecoTECHNOLOGY for Vehicles program, retained the services of the National Research Council Canada to undertake a test program to examine the operational and human factors considerations concerning the removal of the side mirrors on a Class 8 tractor equipped with a 53 foot dry van semi-trailer. Full scale aerodynamic testing was performed in a 2 m by 3 m wind tunnel on a system component basis to quantify the possible fuel savings associated with the removal of the side mirrors. The mirrors on a Volvo VN780 tractor were removed and replaced with a prototype camera-based indirect vision system consisting of four cameras mounted in the front fender location; two cameras on either side of the vehicle. Four monitors mounted in the vehicle - two mounted on the right A-pillar and two mounted on the left A-pillar - provided indirect vision information to the vehicle operator. Four commercial drivers were asked to perform a series of tests simulating typical driving scenarios on a closed course test track. The tests included an object identification test, a blind spot comparison test, a coupling and uncoupling test, a quasi-static lane change test, a dynamic lane change test and an evasive manoeuvres test. The tests were performed both with the mirrors and with the camera-based indirect vision system. The results of the study provide an analysis of driver performance while using the mirrors in comparison to driver performance while using the camera-based indirect vision system. Driver acceptance of the camera-based indirect vision system was also analyzed through the use of questionnaires.

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INTRODUCTION

Indirect vision systems are used by drivers to identify objects that do not fall directly within their line of sight. This can be accomplished through the use of a conventional mirror-based indirect vision system or by a camera-based indirect vision system. Currently, the use of mirror-based indirect vision systems is required on all vehicles as per CMVSS 111 (FMVSS 111 in the United States of America).

Conventional mirror-based indirect vision systems require large structures to be placed in the airflow passing the vehicle creating a significant amount of drag. The use of a camera-based indirect vision system requires smaller support structures, thereby reducing the overall drag coefficient of the vehicle on which they are mounted. The reduction in drag results in fuel savings and a corresponding reduction in emissions.

The purpose of this study is to quantify the possible fuel savings which may be achieved by a highway tractor by using a camera-based indirect vision system and to evaluate the abilities of vehicle operators to effectively operate a heavy-duty vehicle with the use of such a system. To evaluate the preceding, a prototype camera-based indirect vision system was designed and installed on a subject vehicle to allow for

closed course testing of the system by commercial drivers. Component based wind tunnel testing was also performed to evaluate the possible changes to aerodynamic efficiencies accompanying the use of a camera-based indirect vision system in replacement of a conventional mirror-based system.

BACKGROUND

Previous research conducted by the National Research Council (NRC) in their aerospace wind tunnel facilities revealed that the removal of the mirror-based indirect visions systems on a Volvo VN660 highway tractor reduced the drag coefficient of the vehicle by 0.0254 while traveling at 27.8 m/s (100 km/h) [1]. The results of the study suggested that the use of camera-based indirect vision systems could serve as a means to reduce the overall drag coefficient of highway tractors.

In addition to the aerodynamic research performed by NRC, Virginia Tech Transportation Institute (VTTI), in coordination with the National Highway Traffic Safety Administration (NHTSA), performed an in depth evaluation of the requirements of camera-based indirect vision systems [2] [3] [4] [5] [6]. Although the VTTI research did investigate the use of camera-based mirror surrogate systems such as the system described within this paper, their field demonstrations evaluated only driver vision performance. Many of

the findings of the VTTI studies were incorporated into the design of the camera-based indirect vision system tested and detailed within this paper.

TEST EQUIPMENT

Camera-Based Indirect Vision System

The basic design goal for the camera-based indirect vision system was to provide the same visual information through the use of the camera-based system as was available through the use of the conventional mirror-based system. It was important that there was no hindrance to the ability of the driver to operate the vehicle in an effective manner when a camera-based system was used to replace the mirrors. To this effect, it was determined that the fields of view provided by the camera-based system should be equivalent to the fields of view provided by the conventional mirror system.

It was important that the design of the camera system was such that all necessary components were installed solely on the tractor and that no components were required on the trailer. With an estimated three trailers for every tractor operating within Canada, having the system installed only on the tractor lowers overall installation costs. This also eliminates the logistic difficulty of ensuring that a camera-based indirect vision system equipped tractor always be coupled to a compatible trailer.

In order to adhere to the basic design goal of providing the same visual information with the prototype camera-based indirect vision system as is available through the use of a conventional mirror-based system, one camera and monitor was used for each of the mirrors present on the subject vehicle. As a result, there was one camera and monitor pair acting as a unit magnification mirror surrogate and one camera and monitor pair acting as a convex mirror surrogate on each side of the subject vehicle. This resulted in a total of four cameras and four monitors.

The camera selected for the prototype camera-based indirect vision system was a Panasonic WV-CP624 which had a good combination of image resolution as well as day and nighttime viewing characteristics. The selected camera was also infrared (IR) capable for better visibility in nighttime conditions. The selected lens for the camera was a Panasonic PLZ5-50DN with a variable field of view from 5° to 50°. The variable field of view capabilities of the lens allowed for the use of a single camera and lens solution for all four mirror surrogate cameras.

Following on the research performed by VTTI in their development of a performance specification for camera video imaging systems on heavy vehicles [2], it was determined that the optimal location for the cameras was on the front fender of the subject vehicle. As detailed in the VTTI study, the front fender location was selected to maintain a similar sense of depth perception as was available through the mirrors. The mounting of the cameras on the front fender of the subject

vehicle may be seen in [Figure 1](#). The camera in the uppermost position is used as the convex mirror surrogate camera. The camera in the lowermost position is used as the flat mirror surrogate camera. During closed course testing, the cameras were housed inside a temporary steel box to protect the cameras from any road debris but still allow accessibility for the test team in the event access was required.



Figure 1. Cameras mounted on subject vehicle.

Four monitors were mounted on the A-pillars of the subject vehicle, one for each camera. The monitors mounted on the left A-pillar (as shown in [Figure 2](#)) were a ToteVision LCD-562 mounted above a ToteVision LCD-642. The monitors mounted on the right A-pillar (as shown in [Figure 3](#)) were a ToteVision LCD-642 mounted above a ToteVision LCD-842HD. Similar to the placement of the cameras, the size of the monitors was selected in an attempt to maintain depth perception cues, as detailed by VTTI [2].



Figure 2. System monitors mounted on left A-pillar.



Figure 3. System monitors mounted on right A-pillar.

In addition to the cameras and monitors, an IR illuminator was mounted to the side of the subject vehicle to provide additional IR lighting during nighttime driving conditions. The selection of the IR mode on the cameras as well as the powering of the IR illuminator for the prototype system was performed via a toggle switch accessible by the driver of the vehicle.

Subject Vehicle

The subject vehicle for all tests described within this paper was a Volvo VN780 highway tractor with a 53 foot dry van semi-trailer. The vehicle was prepared such that the camera-based indirect vision system and the mirror-based indirect vision system could be interchanged, allowing for comparison testing of the two systems. The subject vehicle with the camera-based indirect vision system may be seen in [Figure 4](#).



Figure 4. Subject vehicle.

Target Vehicle

Four of the six tests which formed the closed course test program required the use of a target vehicle. The target vehicle was a black 2013 Ford Focus Model SE. The target vehicle may be seen in [Figure 5](#).



Figure 5. Target vehicle.

Aerodynamic Test Pieces

In order to perform the aerodynamic testing, two separate camera fairing test pieces were designed. The two camera fairings may be seen in [Figure 6](#).



Figure 6. Camera fairings designed by NRC-AST.

The camera fairing shown on the left in [Figure 6](#) was designed to house the selected cameras and be located on the front fender of the subject vehicle. It was also designed to include a space claim for additionally required items such as a heater to maintain proper operating temperature of the cameras in cold conditions, servos to alter the fields of view of the cameras, as well as space for a lens cleaning system that may be required to clean soiled lenses. The resulting camera fairing was considered a worst case situation. It is expected that a

production version of a camera-based indirect vision system camera fairing would be no larger than the fairing shown on the left hand side of [Figure 6](#).

The camera fairing shown on the right hand side of [Figure 6](#) was designed to house only cameras and to be mounted in the location where the mirrors are conventionally placed. There are a few concept vehicles displaying cameras placed in such a location and it was important to test a similar fairing in order to determine the possible fuel savings through the use of such a camera location.

In addition to the two test pieces designed by NRC, the camera housing developed by VTTI in their field testing of their Advanced Camera/Video Imaging System (A-C/VIS) [6] was also tested. The VTTI developed housing was designed to be placed in the front fender location and house one camera. It was tested as a best case scenario for a front fender mounted camera-based indirect vision system.

Test Subjects

A small sample of test subjects was used to evaluate the camera-based indirect vision system. None of the test subjects had any experience with the use of the camera-based indirect vision system prior to participating in the test program. All of the test subjects were male. [Table A1](#) in Appendix A provides additional pertinent information describing the test subjects. [Table A2](#) in Appendix A provides details of which test subjects completed which tests.

PROCEDURES

Aerodynamic Testing

In order to quantify the fuel savings which may be realized through the use of a camera-based indirect vision system it was important to quantify the gains in aerodynamic efficiency as a result of using such a system. To do so, full-scale component testing of the camera-based indirect vision system components were tested in NRC-IAR's 2 m by 3 m wind tunnel. Each component was tested under a range of wind speeds and wind angles that represent local conditions under which such components might operate when mounted on a vehicle under highway driving conditions.

Because wind tunnel testing was performed on a full-scale component basis only, the mirrors of the subject vehicle also had to be tested. The testing of the mirrors allowed for the comparison of data from previous vehicle testing [1].

In addition to the camera fairings and the mirrors, it was important to determine the contribution to aerodynamic drag due to the installation of an IR illuminator on the subject vehicle. NRC-IAR designed, built and tested a prototype fairing to simulate an IR illuminator housing.

Object Identification Test

The purpose of the object identification test was to compare the test subjects' ability to locate and identify objects while using both the conventional mirror-based indirect vision systems as well as while using the camera-based indirect vision system. The test was completed in both daytime and nighttime ambient lighting for a total of four test conditions. Although weather was not a controlled factor, all tests took place in precipitation free conditions. The object identification test performed during this test program was developed based upon a similar test performed by VTTI while evaluating their Enhanced Camera/Video Imaging System (E-C/VIS) [7].

Four test objects were used for the object identification test: a person, a road cone, a stop sign and a bicycle. The subject vehicle remained stationary throughout the test with the test subject in the driver's seat. The four test objects were presented to the test subject four times each for a total of sixteen object locations tested for each test condition. For each test condition, the test subject was presented the same set of test objects and object locations, but the order of object presentation was altered to ensure the test subject could not predict the location or type of the test object.

To make certain the test subject could not see where the test object was being placed, the indirect vision system under test was obstructed. For the mirror-based indirect vision system, this was accomplished through the use of a spring loaded obstruction operated by a solenoid release mechanism activated via a toggle switch. For the camera-based system, the video feed delivered to the monitors was interrupted via a toggle switch. The subject vehicle engine remained operating throughout the test to prevent the test subject from hearing where the test objects were being placed.

With the indirect vision system under test obstructed, the test team placed a test object in the predetermined object location. Once the test object was in position, the indirect-vision system was unobstructed and the time for the test subject to identify the test object was recorded. The results of the object identification test were analyzed in terms of the proportion of correctly identified test objects and in terms of the time it took for the test subject to locate the test object.

Blind Spot Comparison

The purpose of the blind spot comparison test was to compare the blind spots existing with the mirror-based indirect vision system to those of the camera-based indirect vision system. The test was performed only during daytime lighting conditions. Although weather was not a controlled factor, all tests took place in precipitation free conditions.

The subject vehicle was positioned on an asphalt roadway and remained stationary throughout the test with the test subject in the driver's seat. The target vehicle was positioned roughly 10 m behind the subject vehicle, leaving roughly 1 m of lateral clearance to simulate the target vehicle traveling in an adjacent

lane. The target vehicle was then driven forwards at a speed of less than 2 km/h. The test subject was asked to notify the test team when they could no longer see the target vehicle in the indirect vision system under test. When the test subject could no longer see the target vehicle through the indirect vision system, the target vehicle was stopped and the relative position of the two vehicles was measured. The test was first performed with the target vehicle on the passenger side of the subject vehicle, then with the target vehicle on the driver side of the subject vehicle. The test was performed a total of three times on each side of the subject vehicle. The final position of the target vehicle while using the camera-based indirect vision system was compared to the final position of the target vehicle while using the mirror-based indirect vision system.

Coupling and Uncoupling

The purpose of the coupling and uncoupling test was to determine whether or not the test subject could adequately perform a series of simple coupling manoeuvres which they may be expected to perform during typical transport operations. The test was performed both with the conventional mirror-based indirect vision system as well as the camera-based indirect vision system during daytime and nighttime driving conditions. Although weather was not a controlled factor, all tests took place in precipitation free conditions.

Eight road cones were used to simulate a narrow passage leading to a loading dock. The opening of the narrow passage was 3 m. The subject vehicle was positioned on the test track in a perpendicular orientation to the simulated loading dock, with the near side of the subject vehicle trailer roughly 18 m from the opening of the simulated loading dock. The test subject was then asked to reverse the subject vehicle into the simulated loading dock as they would do during normal operations. Once the test subject was satisfied with the placement of the trailer in the simulated loading dock, the test subject was asked to decouple the trailer from the tractor and pull away from the trailer and return to the starting position. The test subject was then asked to reverse the procedure, reversing the tractor into the trailer, coupling, then driving the combination vehicle out of the simulated loading dock. The procedure was repeated for both driver side and passenger side approaches with both the camera-based indirect vision system as well as with the mirror-based indirect vision system.

The results of the coupling and uncoupling test were analyzed in terms of the time it took for the test subject to satisfactorily position the subject vehicle within the cones of the simulated loading dock.

Quasi-Static Lane Change

The purpose of the quasi-static lane change test was to quantify the ability of the test subject to perceive the location of the target vehicle, while positioned in an adjacent lane, where the longitudinal distance between the front of the target vehicle and the rear of the subject vehicle trailer was 0 m. This location

is referred to as the zero-clearance-distance position of the target vehicle. The zero-clearance-distance position of the target vehicle in relation to the subject vehicle may be seen in [Figure 7](#).



Figure 7. Zero-clearance-distance position of target vehicle.

The quasi-static lane change test was performed both with the conventional mirror-based indirect vision system as well as the camera-based indirect vision system during daytime and nighttime lighting conditions. Although weather was not a controlled factor, all tests took place in precipitation free conditions.

The subject vehicle was positioned on the test track and remained stationary for the duration of the test with the test subject in the driver's seat. The target vehicle was positioned in an adjacent lane, leaving roughly 1.5 m of lateral clearance between the two vehicles. A laser distance meter was attached to the rear of the subject vehicle trailer to continuously measure the clearance distance between the rear of the trailer and a laser reflection panel mounted to the target vehicle.

Once the target and subject vehicles were in position, the target vehicle was driven slowly (<5 km/h) back and forth alongside the subject vehicle for a period of 20 minutes. The test subject was instructed to activate a pendant switch every time they perceived that the rear of the subject vehicle's trailer was flush with the front of the target vehicle's nose.

The same procedure was followed for both driver side and passenger side positioning of the target vehicle, daytime and nighttime conditions and with both the camera-based and mirror-based indirect vision systems.

Dynamic Lane Change

The purpose of the dynamic lane change test was to compare the ability of the driver to perform lane change maneuvers with the indirect vision systems under test. The test was performed both with the conventional mirror-based indirect vision system as well as the camera-based indirect vision system during