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Department of Mechanical Engineering

Final Report

DEMONSTRATION AND EVALUATION OF PLASTIC BAG STREAMLINING ON
HIGHWAY TRUCKS FOR DRAG REDUCTION AND ENERGY SAVINGS

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ABSTRACT

Highway tests on a tractor-trailer with and without a rear-door drag reduction device have demonstrated a 13 horsepower savings for an 88" x 94" rear door at a vehicle speed of 55 mph. Greater savings would be realized for larger trailer door sizes and higher highway speeds. Implementation of such devices on high-use vehicles would provide a payback period of less than a year for installation of rear-door drag reduction devices.

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DRAG REDUCTION DEVICES FOR HIGHWAY TRUCKS

Introduction

For several years highway trucks have been using cab deflectors for reduction of aerodynamic drag on the front end of the tractor-trailer. Studies of bluff-body drag show that about 70 percent of the drag comes from the front end; the remaining 30 percent is due to the drag at the rear end and under-carriage. A tractor-trailer is not a strictly bluff body. The projected cross-sectional area is large, however, and large drag forces are associated with the movement of these vehicles at speeds of, say, 55 mph. Because of the national emphasis on fuel conservation, the University of Alabama, under a grant from DOE initiated a research project to actually measure these drag forces on the rear end of highway trailers. This report is a summary of those findings.

Early in the project Dr. Keith Koenig, Professor of Aerospace Engineering at Mississippi State University was contacted and interviewed regarding our plans. Dr. Koenig's dissertation was an investigation of bluff-body drag. He made available much of his literature, for which we are grateful. He also indicated that little work has been performed on the rear end because there was such greater potential savings by streamlining the front end.

The object of our work was to use a scale-model truck in a wind-tunnel to select a particular air-foil and to build

this air-foil for a medium size highway tractor-trailer. Furthermore, the vehicle was instrumented such that we measured air velocity and direction, draw-bar pull, and rear door forward force. These data were collected for flatback and streamlined conditions at speeds from 40 to 60 mph. From these data we evaluated the advantages of the rear door streamlining.

Procedure

The first task of our project was to review the literature in this field. We found a patent on a rear door streamlining device. We found several articles in the literature indicating that wind-tunnel and highway studies were being performed on trucks and buses. We found little or no data showing how much benefit could be realized. Furthermore we found the instrumentation for such evaluations deficient.

Secondly we designed a model truck and performed wind-tunnel tests on the bluff body and with several rear-door drag reduction devices. From these tests we selected a shape for the rear door of the full scale tests.

Thirdly we developed an instrumentation package for the truck. This system included a wind speed velocity and direction transducer mounted about eleven feet above the road and in front of the truck tractor. These transducers were mounted on a pipe frame in order to measure the undisturbed region of the air. A draw-bar load cell was designed, built, and mounted on the tractor's fifth wheel. This 10,000 pound

strain gage load cell measured the actual draw-bar force transferred from the tractor to the trailer. We also disconnected the rear door on the trailer, mounted it on a frame, placed the frame in four linear bearings, mounted the bearing housings to the trailer floor, and tied the door to the trailer floor through a 1000 pound strain gage load cell. Plastic sheeting sealed the gap between the door and the trailer walls. The load cell measured the integral of the $(p)(dA)$ on the inside and outside surface of the door. We actually found that the door force was forward (i.e., pushing) when we had the stream line device in place. We recorded the data from the two load cells and the air velocity and direction transducers on a data logger and we could also record individual signals on a strip chart recorder. At first we noticed a large scatter in the loadcell data. When we examined the signal on a continuous recorder we observed a periodicity to the signals and the peaks and valleys were reproducible. We were observing vortex formation and shedding on the flat-back rear door. The force on the door was very sensitive to the presence or absence of vortices. We also observed that crosswinds influence the formation and loss of the vortex.

Results

Wind-tunnel tests. The five shapes were evaluated on the model door in a low speed wind-tunnel. Because of the model size, only low reynolds numbers were produced for our study. These tests, nevertheless, gave relative ranking to the several

designs. We were able to measure the drag force with a wind-tunnel sting balance. Liquid air was bled to the front of the model to visualize the air flow, vortices, stagnation points, and under carriage air flow. A false floor was used to simulate the road. From the several evaluations one design was selected for construction of a 94" x 88" door for our test truck. A gasoline generator was installed to power the instrumentation in the trailer. Several holes were present in the floor of the trailer which provided static stream pressure inside the trailer. This pressure was subatmospheric when the trailer was moving. The streamline shape was made from plywood.

Full-scale truck tests. The fifth wheel load cell gave an output which was sensitive to engine torque, road tilt, tire pressure, and included several dynamic components which could not be positively identified at each instant in the record. The rear door load cell, however, was related primarily to the integrated air pressure around the door. The inertial and gravitational forces were small. We noticed that we had considerable scatter in the digital data-logger signal. We recorded the load cell on a strip chart recorder and observed vortex shedding. We identified several of the aerodynamic forces on the rear door. Furthermore we observed a forward net force with the stream line because the inside of the trailer had vent holes that place the trailer at the static stream pressure which was subatmospheric. The net force on

the door was positive, or forward. To confirm this we placed a small window on the front face of the trailer and opened this window on several runs which produce the stagnation pressure inside the van. Actually we did not achieve the total stagnation pressure because of flow conditions through the trailer. We were able to view the changes in rear door force and we have confidence that the aerodynamic drag force must be measured with a mechanically isolated door, and an accurate interior pressure must be measured with and without the streamline device.

The results are shown in Figures 1-4. The vehicle velocity versus flatback door force for window open and window closed condition are shown in Figure 1. The velocity versus negative (or forward) door force is shown in Figure 2 for the drag reduction device attached. Figure 3 shows the horsepower savings produced by adding the rear door air foil. At 55 mph the force reduction is 89 pounds which is equivalent to a 13 horsepower savings.

Figure 4 shows the horsepower savings for this size vehicle and the projected savings for a large trailer (8" x 10" door). At 65 mph a 29 horsepower savings is realized for an 8" x 10" door. Converting the horsepower to fuel savings, one can project a payback period of less than a year if the truck sees heavy use.

A deployable and inflatable plastic or rubber-fabric bag was designed for this truck. A spring held the bag

against the rear door at low speed. At high speed, the forward pressure would inflate and stretch the bag behind the vehicle. We did not have sufficient time to eliminate flapping and instability of the bag. The heavier bag lowers the flap frequency and gives the bag rigidity. Some internal stiffeners are needed. We believe that a bag attached to one of the rear doors can be developed that will inflate only at significant highway speeds and at low speeds will be drawn against the rear door thus giving full vision at the rear of the trailer.

Conclusions and Recommendations

From the road tests of an 88" x 94" flatback tractor-trailer we conclude that a 13 horsepower savings at 55 mph is available by the use of a simple drag reduction device. Larger sized trailers and higher highway speeds will yield higher savings.

It is recommended that a fleet of highway tractor-trailers implement a rear door drag reduction device. These data must be carefully and accurately obtained and compared with a similar group of test vehicles without the drag reduction device.

FLATBACK

Figure 1

Fig 2

ATTACHMENT ON

WINDOW CLOSED

Figure 3

Figure 4