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Noise Reduction Technology and Costs for a Ford CLT 9000 Heavy-Duty Diesel Truck

Environmental Protection Agency

October 1981

Demonstration Truck Program

2

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This is one in a series of seven technical reports and a program summary prepared for the Environmental Protection Agency's Demonstration Truck Program. The reports in this series are listed below.

Report Number	Title	Date
1.	Program Summary, Truck Noise Reduction (BBN Report No. 4839).	December 1981
2.	Noise Reduction Technology and Costs for a Ford CLT 9000 Heavy-Duty Diesel Truck (BBN Report No. 4379).	October 1981
3.	Noise Reduction Technology and Costs for a General Motors Brigadier Heavy-Duty Diesel Truck (BBN Report No. 4507).	October 1981
4.	Noise Reduction Technology and Costs for an International Harvester F-4370 Heavy-Duty Diesel Truck (BBN Report No. 4667).	October 1981
5.	Noise Reduction Technology and Costs for a Mack R686 Heavy-Duty Diesel Truck (BBN Report No. 4795).	December 1981
6.	Field Test of a Quieted Ford CLT 9000 Heavy-Duty Diesel Truck (BBN Report No. 4700).	October 1981
7.	Field Test of a Quieted General Motors Brigadier Heavy-Duty Diesel Truck (BBN Report No. 4796).	December 1981
8.	Field Test of a Quieted International Harvester F-4370 Heavy-Duty Diesel Truck (BBN Report No. 4797).	December 1981

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16. ABSTRACT

This report discusses the technology and costs required to reduce the noise of a Ford CLT 9000 heavy-duty diesel truck from 77.1 to 72.3 dBA. The noise control treatment consists primarily of a dual exhaust silencing system and a partial enclosure for the engine and transmission. Wind tunnel tests on the completed truck show that temperatures of engine coolant and oil remain within manufacturer's specified limits. The noise treatment increases the vehicle weight by 397 lb and estimated vehicle price by $1309.

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NOISE REDUCTION TECHNOLOGY AND COSTS FOR A FORD CLT 9000 HEAVY-DUTY DIESEL TRUCK

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PREFACE

This report deals with the technology and costs of treatments developed and implemented by Bolt Beranek and Newman Inc. (BBN) to reduce the noise level of a Ford CLT 9000, one of the heavy-duty diesel trucks in the Environmental Protection Agency's Demonstration Truck Program. This program, begun in 1979, included four heavy-duty diesel trucks, each with a different engine. The original program plan called for each vehicle to receive noise reduction treatments and then to enter fleet service for a year of field testing. Each of the four vehicles successfully completed the noise reduction part of the program. The duration of the program was shortened from the original plan; thus only two of the vehicles completed an entire year of field testing. The third truck was in supervised field service for five months, and the fourth truck did not enter fleet service.

The focus of the Demonstration Truck Program was on the technology of treating the vehicles, rather than components such as engines or tires. The EPA conducted parallel programs on diesel engine and tire noise control; these other programs were to be integrated with the truck program. Accordingly, BBN's treatment was primarily to add mufflers for exhaust noise control, enclosures for engine and transmission airborne sound, and vibration isolators for engine structureborne sound where required.

Seven final reports and a program summary were prepared by BBN for the Demonstration Truck Program. Their titles are listed on the inside cover of this report. The reports appeared in draft version beginning in early 1980 and extending through 1981. The final version of each report was prepared in late 1981. Each of the reports is intended to be internally complete; therefore, some redundancy occurs among the four technology and cost reports. For example, a reader who has already read one technology find that he can pass over the nearly identical introduction and test requirements sections (Sec. 1 and Appendix A) and focus on the remaining sections that contain unique technical material.

The authors are grateful to the many governmental and industrial organizations and personnel who have contributed to the development of this truck. The program has been sponsored by the Environmental Protection Agency's Office of Noise Abatement and Control. The Ford Motor Company provided technical information and arranged with the Modine Manufacturing Company for wind tunnel testing of the treated truck. The Donaldson Company supplied the exhaust silencing system and Tech Weld fabricated many of the engine enclosure components. Noise testing was done at Hanscom Field with the cooperation of the Charles Stark Draper Laboratory and the Massachusetts Port Authority.

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I. INTRODUCTION

The primary objective of the project described in this report has been to reduce the noise level of a Ford CLT 9000 heavy-duty diesel truck from 77 to 72 dBA at 50 ft. This target level, established by EPA, is 8 to 10 dBA lower than that typically produced by heavy-duty diesel trucks in current production. This 72-dBA level has been reached by only four roadworthy U.S. trucks in recent history [1-4]. An additional objective, also established by EPA, has been to ensure that cab noise levels do not exceed 78 dBA. This level corresponds to a proposed interior bus noise level of 80 dBA [5] less 2 dBA to account for manufacturing tolerances.

To be acceptable, the noise treatment must allow the truck to function normally. Accordingly, the treatments must be durable, interfere as little as possible with maintenance activities, add as little weight as possible, permit continued adequate component cooling, and have minimal impact on engine efficiency. All of these factors may be characterized in terms of equipment and operating costs. Projections of initial equipment costs are treated here; operating costs are discussed in the companion field service report [6].

The technical approach to the development of noise treatment for the Ford CLT 9000 has involved four major phases:

I. Baseline noise testing

II. Development of noise control treatments

III. Final noise and cooling test

IV. Equipment cost estimation.

In the first phase, the untreated vehicle is noise-tested at EPA's Noise Enforcement Facility at Sandusky, Ohio. The vehicle is then delivered to BBN's facility in Cambridge, Massachusetts, where in-cab and exterior noise measurements are conducted. Diagnostic tests are performed to determine contributions from major noise sources (exhaust, tires, engine, and transmission). Quantitative goals for each source are also established and compared to the actual noise contributions. The differences then become the noise reduction objectives that must be achieved by each treatment for the entire vehicle to reach the 72-dBA level.

In the second phase, we develop the noise treatment, which consists primarily of an exhaust silencing system and an engine/-transmission enclosure. The exhaust system is first laboratory tested to ensure that it meets our goals and then installed on the truck. An enclosure mock-up, built of 1/4-in. masonite and fiberglass, is tailored to the vehicle. These inexpensive and easy-to-form materials are used largely because of the cut-and-fit approach needed to conform to the complex geometry associated with the truck and its many components.

After a suitable mock-up enclosure is developed and tests are performed to indicate that goals have been met, the enclosure is fabricated from metal and sound-absorptive materials and installed in a nearly final form. In this phase, some refinements are implemented as needed to tune the system acoustically, thereby bringing the vehicle into closer compliance with the goals.

In Phase III, the truck undergoes final noise testing at EPA's official Noise Testing Facility at Sandusky, Ohio, and wind tunnel testing to ensure that cooling requirements are met. In addition, the vehicle and available data are reviewed by EPA, the vehicle manufacturer, and the fleet operator, to verify, insofar as practicable, that the vehicle is ready for service.* The technical development is then complete, and the truck enters fleet service.

While costs are taken into account qualitatively in the numerous decisions made throughout the program, a formal cost assessment is deferred until the vehicle is complete. At this point (Phase IV) a formal detailed equipment cost analysis is performed.

Section 2 of this report describes the baseline truck and the noise source levels associated with its major components. Section 3 presents a discussion of the noise treatment. The final interior and exterior test data are summarized in Sec. 4. The performance of the engine cooling system is evaluated in Sec. 5, and the incremental costs and purchase prices associated with the noise treatment are estimated in Sec. 6. Noise test procedures are briefly summarized in Appendix A.

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*Members of the reviewing organizations apply engineering judgment but do not conduct detailed engineering analyses or tests.

2. BASELINE TRUCK CONFIGURATION AND NOISE LEVELS

2.1 Truck Description

The baseline truck, as received by BBN at the beginning of the noise treatment project, is illustrated in Fig. 1. It is a 1978 model CLT 9000 cab-over-engine 6 x 4 tractor with a 152-in. wheel base. The sleeper type cab, which is 88 in. long (BBC) is suspended at each corner by a pneumatic spring for ride control. Fully fueled and with a driver, the tractor weighs 18,220 lb; it has a gross combination weight rating (GCWR) of 80,000 lb.

FIG. 1. BASELINE TRUCK CONFIGURATION.

The engine, a Caterpillar model 3406 PCTA, is a four-stroke-cycle, in-line, six-cylinder diesel. Each cylinder is equipped with a precombustion chamber, and the engine has a turbocharger and an after cooler (designated by PC, T, and A respectively in the suffix to the model number). The engine has an 893-cu-in. (14.6L) displacement and is rated at 340 hp at 1950 rpm. A governor limits the maximum engine speed to about 2250 rpm.

As illustrated in Fig. 2, engine intake air enters through a duct at the front of the truck just above the radiator and passes through an air cleaner, which is a 9-in.-diameter Donaldson model

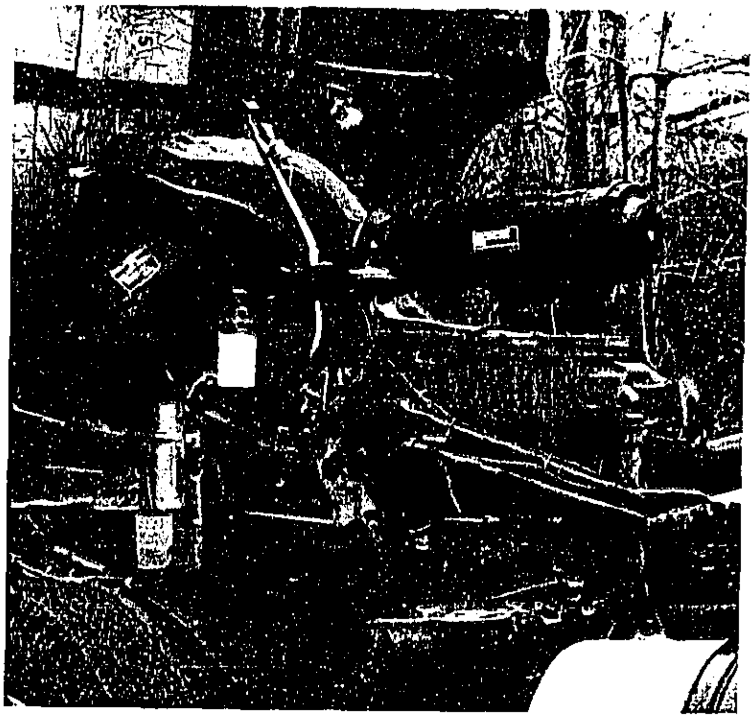

FIG. 2. FRONTAL AIR INTAKE, AIR FILTER, AND ENGINE WITH CAB TILTED FORWARD.

EBA09-2013. The air then enters the turbocharger (not visible in Fig. 2) where it is compressed and subsequently cooled by the after cooler before being ingested by the cylinders.

Figure 1 shows that the baseline truck is equipped with a single vertical exhaust system. The exhaust piping consists of a section of 5-in.-diameter stainless steel flex hose and aluminized steel tubing. The exhaust muffler, Donaldson model WFM10-0201, has a nominal 10-in.-diameter double body and a standard 44-1/2-in. body length.

As may be seen in Fig. 3, the cooling fan is thermostatically controlled. The fan has a 32-in. diameter and six evenly spaced stamped sheet metal blades. The viscous fan clutch is an

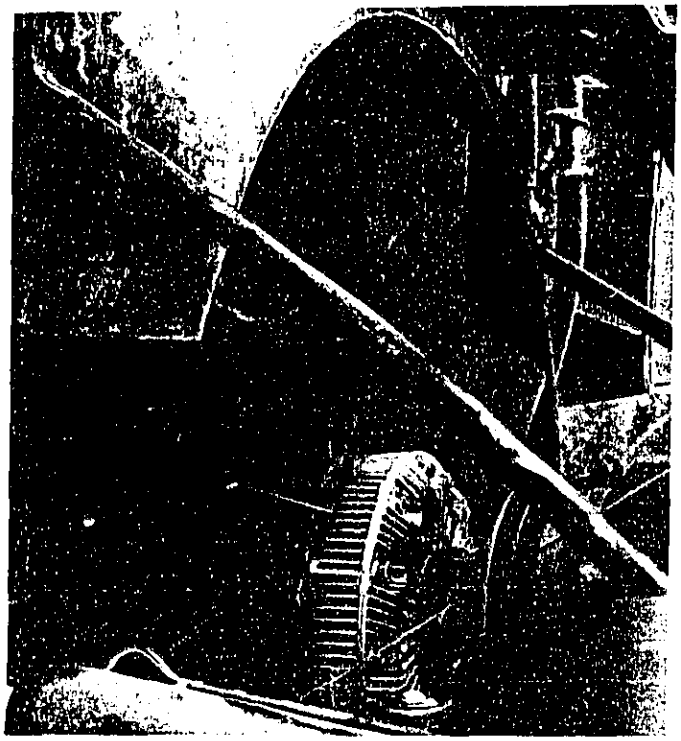

FIG. 3. FAN AND SHROUD.

Eaton model 340, which turns on at an air temperature of 165° to 170°F. The fan-pulley to engine-pulley ratio is 1.1. When the fan is on, it turns at 95% of fan pulley speed or 5% over engine speed. As shown in Fig. 3, the fan is shrouded, but the shroud has a cutout on the left side. This section is reportedly left open to accommodate fan/shroud clearances that vary depending on the engine model used in this vehicle. (The shroud is common to all engines.) There was no clearance problem associated with the Caterpillar engine and, to enhance cooling performance, we riveted a strip of metal across the opening to follow the shroud's circular contour.

The transmission and rear axles are manufactured by the Eaton Corp. The transmission, a Fuller (division of Eaton) model RTO-12513, has 13 forward speeds. The model DS-308 tandem drive rear axles have a 4.33 speed ratio.

All wheels were equipped with Firestone 10.00 x 22 bias ply tires with ribbed tread patterns. These tires were selected for their lower noise levels compared to the cross bar tread commonly used on tractor drive axles.

2.2 Baseline Noise Levels

The truck was initially noise-tested by EPA at its Noise Enforcement Facility at Sandusky, Ohio, and subsequently by BBN at Hanscom Field in Bedford, Massachusetts. Both tests were performed in accordance with the test procedure prescribed by EPA in 40 CFR 205 [7]. This test is very much like the SAE J366b test; it involves accelerating the vehicle at full throttle from an initial low speed (of about 9 mph for this truck) to a final speed at which maximum governed speed is reached. Noise levels are measured by a microphone located 50 ft from the vehicle's line of travel.

Table 1 shows that the exterior noise levels measured at each location are within about 1 dBA of each other. We will use 77.1 dBA as the baseline level for consistency with most of the tests conducted by BBN.

TABLE 1. BASELINE OVERALL NOISE LEVELS.

	EPA Measurements (dBA)	BBN Measurements (dBA)
Left Side	76.0	77.1
Right Side	76.4	75.8
In-Cab	--	77.1*

It is useful to know the approximate initial contributions of major noise sources on which to base the design of noise treatments. Laboratory and field tests were conducted to determine the contributions from exhaust, intake, engine and transmission, and tire and aerodynamic sources. However, it should be remembered that, while these levels provide guidelines for the development of noise treatments, they are of only secondary importance to the levels of the treated components and complete truck. Therefore, we seek reasonable levels of accuracy (e.g., ±2 dBA) and do not feel that greater precision for these tests would justify significantly greater resource investment than is reported here.

Intake Noise

The baseline intake noise level was measured under laboratory conditions at the Donaldson Company's facility. The experimental configuration is shown in Fig. 4. The laboratory consists

*This is the peak A-weighted level and not the sum of the A-weighted band levels.

of an area inside a building, housing a test engine and dynamometer, and an outdoor area in which key components and a microphone are located. The acoustic wall shown in the figure is part of the building and is constructed of a double wall of concrete and an exterior foam surface. The concrete is sufficiently thick to attenuate noise radiated by the engine to negligible low levels. The sound-absorbing foam is intended to minimize the contribution of intake noise that is reflected from the concrete wall. Engine exhaust is piped to a remote location where it is highly muffled. A metal shield has been placed between the intake and the microphone, as shown in Fig. 4, to simulate the effect of the cab on the radiated sound field.

Because intake noise levels were relatively low, a microphone was placed 75 in. from the intake duct so that an adequate

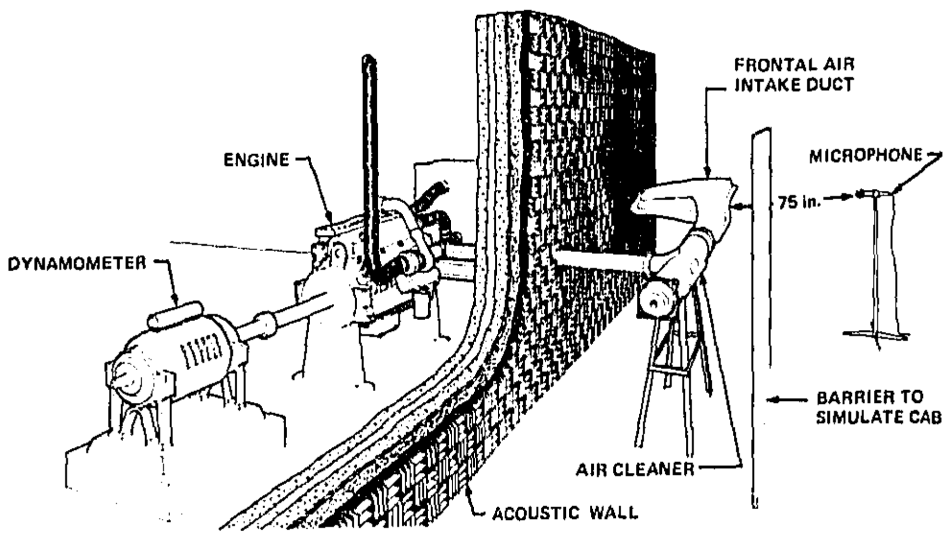

FIG. 4. EXPERIMENTAL CONFIGURATION FOR INTAKE NOISE MEASUREMENT.

signal-to-noise ratio could be obtained. To simulate the operational conditions that occur during a truck passby test, the engine is accelerated, using only the rotary inertia of the dynamometer as a load. (Donaldson has found that levels measured by this technique correlate well with passby measurements.) The noise level measured under these conditions was 78 dBA, which, when 18 dBA are subtracted, extrapolates to 60 dBA at 50 ft. This extrapolation assumes 6 dB of attenuation per doubling of distance.

Tire and Aerodynamic Noise

In addition to the major noise sources that require treatment, secondary sources such as tires, aerodynamic flow, and other components contribute to the overall level. To estimate the contribution from these sources, coastby tests were conducted; these tests provide particularly good indications of tire and aerodynamic noise. Figure 5 shows the data plotted on a

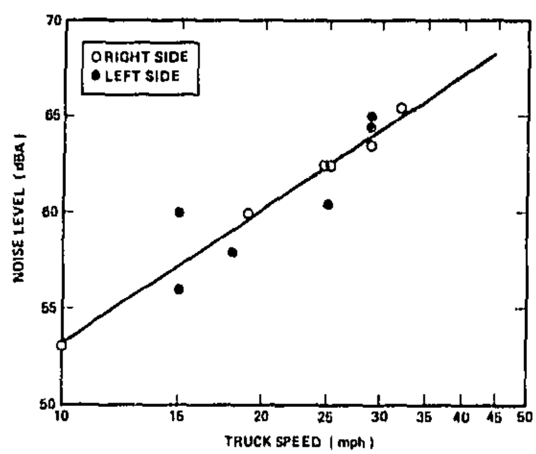

FIG. 5. VEHICLE COASTBY LEVELS.

logarithmic scale along with a least squares linear regression curve. The data illustrate that the contribution is approximately 60 dBA at the maximum speed of 20 mph reached during 40 CFR 205 tests.

Exhaust Noise

Estimates of the exhaust noise levels were developed from laboratory tests conducted as described above for intake noise measurements. For exhaust noise tests, however, the microphone was located 50 ft from the exhaust stack. Exhaust noise levels of 69 dBA were measured under the laboratory conditions described above with the 3406 DIT engine at 280 hp and the baseline WFM10-0201 muffler. While exhaust levels have not been measured for the 340-hp 3406 PCTA engine equipped with a WFM10-0201 muffler, one may use other data to estimate these levels with an acceptable degree of confidence. Straight pipe source levels for a 375-hp 3406 engine were about 1 dBA higher than the levels for the corresponding 280-hp 3406 DIT engine. One would reasonably expect the source level for the somewhat lower powered 340 hp engine to be about 1 dBA less than the 375-hp PCTA version, or approximately the same as the 280-hp 3406 engine. Accordingly, the muffled exhaust level for the baseline engine and exhaust system is estimated to be about 69 dBA.

Engine and Transmission

The baseline truck was received with the following external engine and transmission treatment installed:

- Engine block panels
- Oil pan enclosure
- Undercab sound-absorptive foam

- Transmission under shield
- Transmission side shields.

(The first three treatments were left in place when BBN developed additional noise treatments; the transmission side and under shields were removed.)

For purposes of this project, the engine and transmission are treated as a single source, around which an acoustical enclosure is to be built. The noise contribution from the engine/transmission combination is estimated by logarithmically subtracting the levels of the other major known sources (exhaust, intake, tires, and aerodynamic) from the measured overall level of 77.1 dBA. The resulting 76.2-dBA level shows that the engine/transmission level is very close to the overall level.

2.3 Summary of Component Levels

Figure 6 provides an overview of the major noise source levels for the vehicle in its initial or baseline configuration and the goals for the treated sources. The figure clearly shows the dominance of the engine and transmission, with the exhaust second and the intake, tires, and aerodynamic sources at significantly lower levels. The goals reflect some judgment as to the feasibility, reasonableness, and costs of silencing each source.

The state of the art of flow silencers is sufficiently well developed to make a 9-dBA reduction, from 69 to 60 dBA, a reasonable goal for exhaust and intake systems. This reduction is believed feasible with a dual system incorporating off-the-shelf equipment. The initial intake noise level is 60 dBA and requires no further treatment. At 60 dBA each, the intake and exhaust systems contribute 63 dBA together. Reducing their contribution further results in only about 0.11 dBA of reduction in overall level per dBA reduction in their combined levels. Therefore, no further reduction in these levels seems warranted.

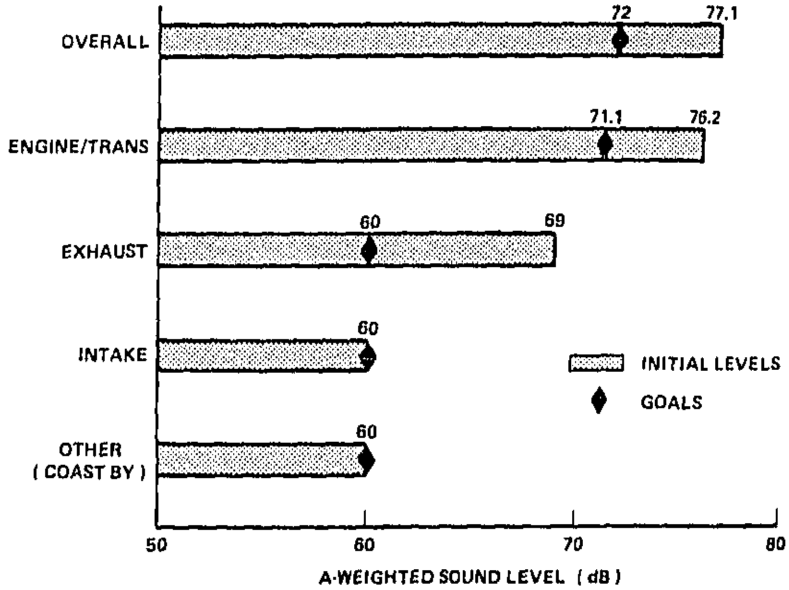

FIG. 6. OVERVIEW OF MAJOR NOISE SOURCE LEVELS AND GOALS.

With the exhaust noise level reduced by 60 dBA, and the intake and other levels each maintained at their initial 60-dBA levels, the engine/transmission goal becomes 71.1 dBA. This represents a 5.1-dBA reduction, which we planned to achieve by means of a tunnel-like enclosure.

3. NOISE CONTROL TREATMENTS

Two major treatments were used to reduce the noise of the Ford CLT 9000 truck. The treatments are:

- Modifications to the exhaust system
- Installation of an engine/transmission enclosure.

Sections 3.1 and 3.2 describe these treatments in detail.

3.1 Exhaust System

The dual exhaust system installed on the vehicle is shown in Fig. 7. A 5-in.-diameter exhaust line, consisting of aluminized steel tubing and stainless steel flex hose, leads from the Turbocharger to a Splitter Tee Can (Donaldson Model MAM10-0059). The Tee Can provides some muffling and splits the flow into dual 4-in. exhaust lines. Each line contains a nominal 10-in.-diameter double shell cylindrical muffler (Donaldson Model WTM10-0066) and a 4-in. stack silencer (Donaldson Model AEM00-1338). The Super Stack Silencer, as it is designated by Donaldson, has a 3-in.-diameter perforated liner made of aluminized steel, fiberglass packing, and a pressure recovery cone at the outlet. Note that it was necessary to add a stock Ford exhaust stack mast and mast bracket to the left side of the vehicle to accommodate the dual system.

Exhaust noise levels were measured for a single branch of the exhaust system, under laboratory conditions, as discussed in Sec. 2.2. For these tests, a Caterpillar 3406 DIT engine rated at 280 hp was used and A-weighted octave band sound levels were measured. As indicated earlier, the source level for this engine is approximately the same as for the truck-mounted 3406 engine at 340 hp. Adding to the measured data 2 dBA to account for the presence of two exhaust lines on the truck gives the spectrum shown in Fig. 8. Also shown in this figure are the A-weighted

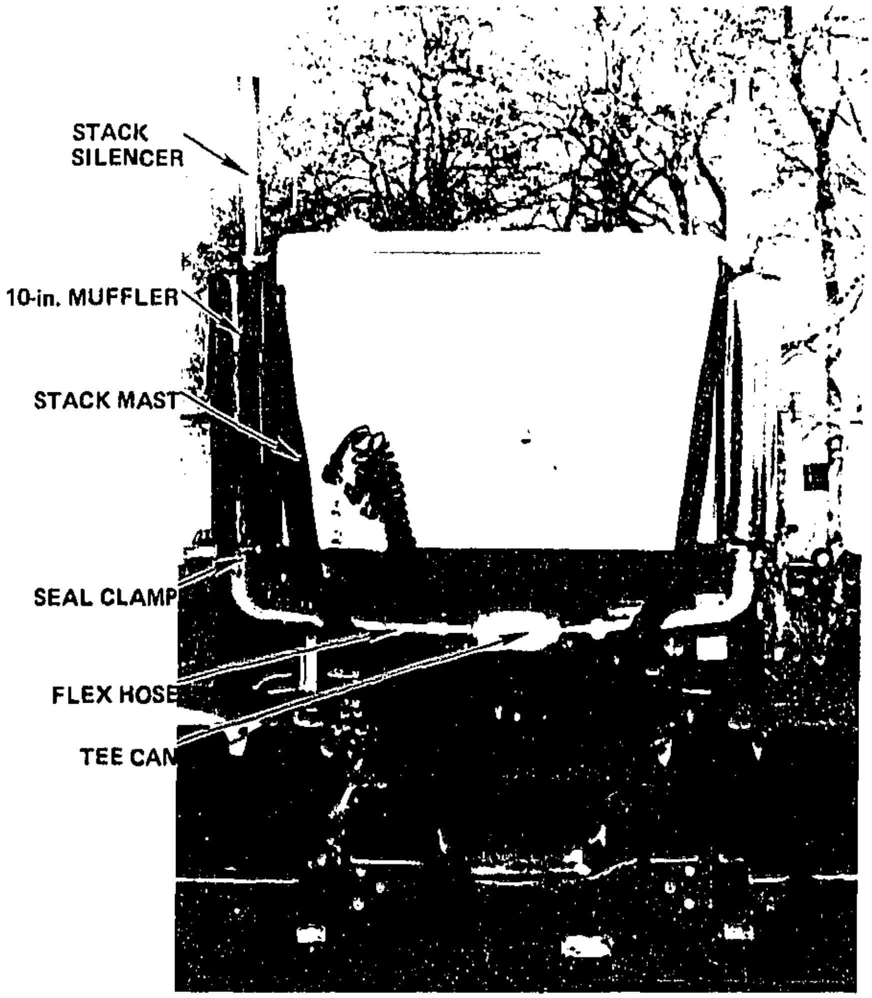

FIGURE 7. DUAL EXHAUST SYSTEM.

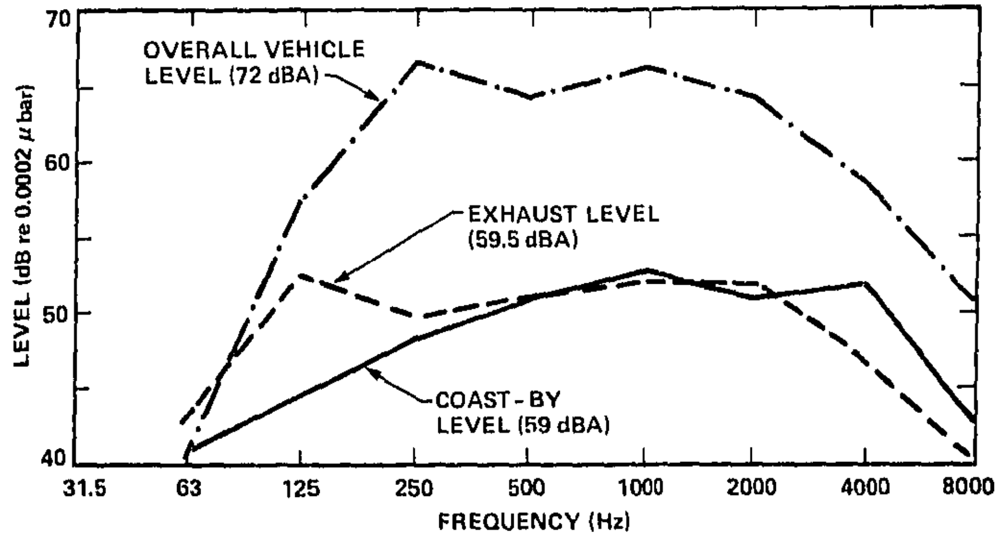

FIG. 8. ESTIMATED A-WEIGHTED OCTAVE BAND SPECTRUM OF EXHAUST NOISE: COMPARISON WITH OVERALL VEHICLE AND COASTBY SPECTRA.

octave band spectra of the final truck configuration and the noise floor established by coastby-tests. The estimated exhaust noise level is about 10 to 15 dB below the overall vehicle level in all frequency bands except the 63- and 125-Hz bands, which are sufficiently low to be of little consequence. The reason the estimated exhaust noise level appears higher than the overall vehicle level in the 63-Hz band is not known with certainty, but probably relates to short time-bandwidth products associated with low-frequency spectral analysis and to different acoustic interference effects associated with field and laboratory tests.

3.2 Engine Transmission Treatment

The baseline contribution of the engine and transmission to the overall noise level was estimated to be 76.2 dBA. This source was treated with an acoustical enclosure built around the engine/transmission.

The enclosure components are illustrated in Fig. 9 and identified in Table 2. The following overall design objectives guided the design of the enclosure:

- Adequate noise reduction
- Minimal effect on engine cooling performance
- Minimal maintenance interference
- Simplicity and ease of construction
- Durability
- Protection of sound-absorptive material from environmental contaminants
- Light weight.

TABLE 2. DESCRIPTION OF ENCLOSURE NOISE TREATMENTS.

Identifier	Description
L1, R1	Left and right cab-mounted shields
L2, R2	Left and right shelf assemblies
L3, R3	Left and right vertical assemblies
L4, R4	Left and right sound-absorptive package on vertical assemblies
B1, B2, B3	Panels forming bottom of the bellypan
T1,T2	Forward and rear transmission covers.

Enclosure Design Concept

A tunnel enclosure was designed to shield the community from engine and transmission noise. The enclosure is open at the front and rear of the truck to allow cooling air to flow through the radiator, over the engine and transmission, and out the rear. As illustrated in Fig. 9, the bottom of the cab provides the top of the enclosure. The remaining major areas requiring treatment to complete the enclosure are:

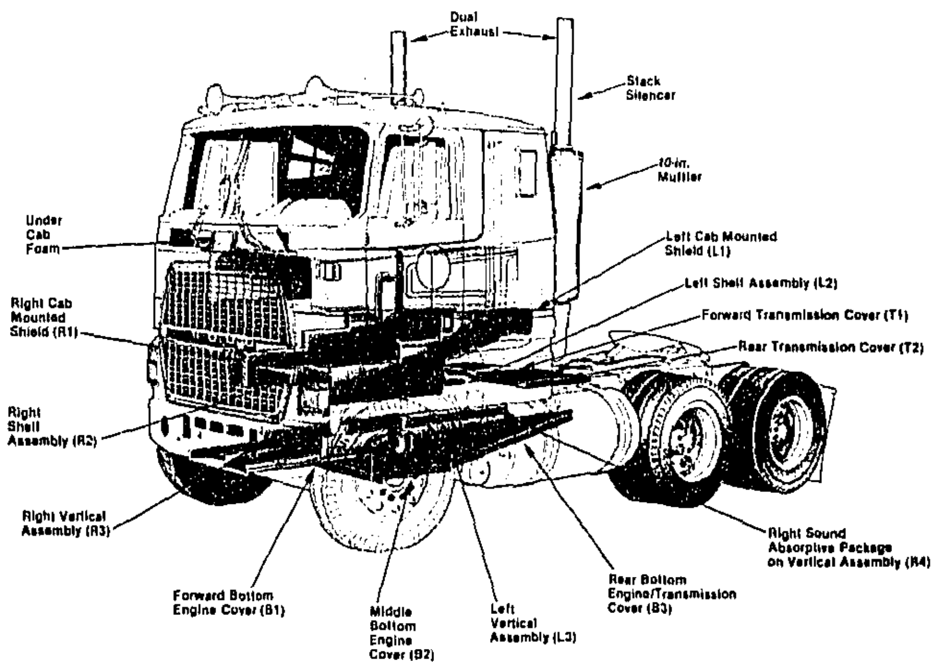

FIG. 9. NOISE CONTROL TREATMENTS INSTALLED ON FORD CLT 9000.

- The area between each frame rail and the bottom of the cab
- The bottom of the engine between the frame rails
- The top of the transmission, above the frame rail.

The area between each frame rail and the bottom of the cab is enclosed by a side shield and a shelf (R1, R2 and L1, L2, in Fig. 9). The bottom of the engine is enclosed by the bellypan, which is supported between the two frame rails. The area above the transmission is enclosed by the walk plate and a transmission top cover that extends in front of the walk plate.

The enclosure is fabricated predominantly from sheet aluminum. While we anticipate that a truck manufacturer would use an alternative material (e.g., sheet steel), sheet aluminum provides a light, rigid material well suited to prototype work. A minimum panel thickness of 1/8 in. was dictated by apparent requirements for strength and durability rather than for noise reduction.

To ensure that 1/8-in. aluminum provides sufficient acoustic attenuation, we may estimate the transmission loss of these panels. Figure 10 shows the predicted transmission loss (TL) as a function of frequency for a 1/8-in. panel using the "plateau method" discussed in Sec. 11.3.5 of Ref. 8. Applying this TL function to the approximate baseline engine spectrum shown in Fig. 11 provides an estimated spectrum of sound transmitted from the engine and transmission through the aluminum panels. This transmitted contribution, also shown in Fig. 11, has an overall A-weighted value of 48.5 dBA, which is so far below the total vehicle goal to be of no material consequence.

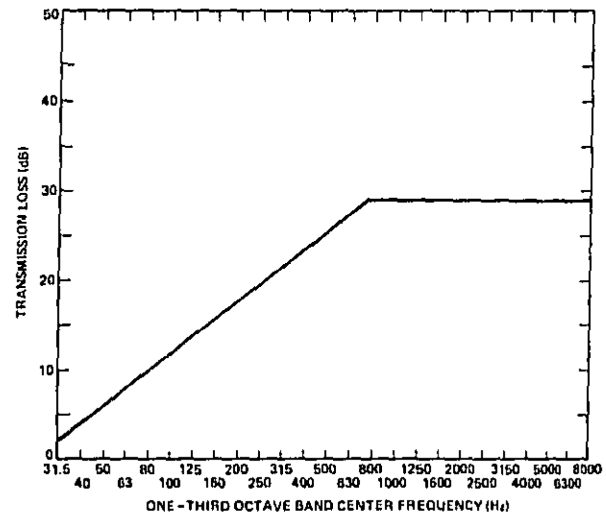

FIG. 10. ESTIMATED TRANSMISSION LOSS OF 1/8-IN. PANEL.

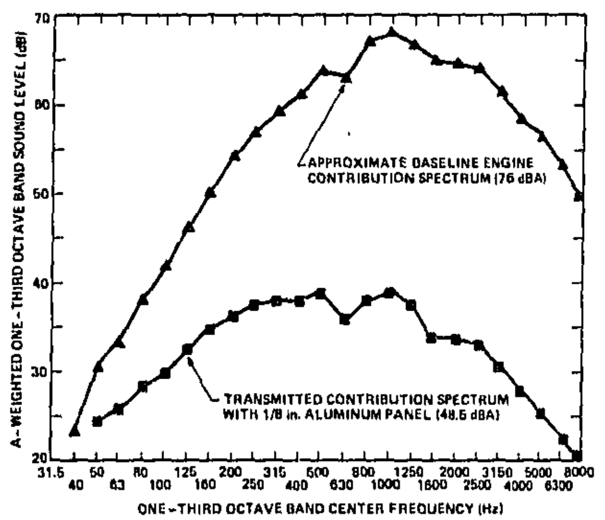

FIG. 11. ESTIMATED SPECTRAL CONTRIBUTIONS OF SOUND TRANSMITTED THROUGH ENCLOSURE PANELS.

Sound-Absorptive Material

Two types of sound-absorptive material are used in the tunnel enclosure:

- Ford baseline 1-in. polyester-faced foam
- BBN-installed 1.5-in. Mylar-wrapped fiberglass.

The baseline truck was received with polyester-faced foam under the cab. This is identified as undercab foam in Fig. 9. This material is 1-in. open-cell urethane foam with a 1.5-mil aluminized polyester facing and a pressure-sensitive adhesive backing.

A drawing of the Mylar-wrapped fiberglass construction, used for additional treatment, is shown in Fig. 12. The basic absorptive material is 1.5-in. Owens-Corning 704 Fiberglas board.

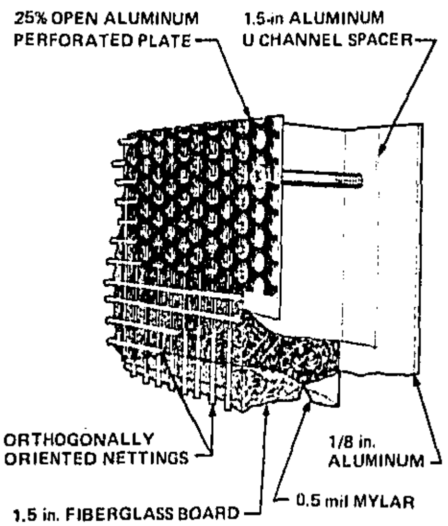

FIG. 12. DRAWING OF MYLAR-WRAPPED SOUND ABSORPTIVE TREATMENT.

A similarly shaped piece of nylon netting with 1/16-in.-thick strands is placed on top of the fiberglass. The netting and fiberglass are wrapped in one piece of 0.5-mil Mylar, with the seam on the bottom sealed with 4-in.-wide Mylar tape. Another layer of netting is placed on top of the Mylar. The layered composite is then sandwiched between the 1/8-in. panel aluminum base plate on the bottom, and a 25% open 1/16-in. perforated aluminum plate on the top. A 1.5-in. aluminum U channel seals the edge and provides the 1.5-in. spacing.

The construction described above is a conservative design that provides a relatively high degree of sound absorption with protection from contaminants and mechanical damage. The Mylar prevents the fiberglass from soaking up oil and water. Suspended between two plastic nets, the Mylar is free to oscillate with incident sound waves, thereby transmitting most of the incident acoustic energy to the fiberglass, where it is partially absorbed. Without the netting, the Mylar would be constrained by the fiberglass and perforated aluminum and would reflect a greater portion of the incident sound. The perforated aluminum protects the very thin and somewhat fragile Mylar from damage by such mechanical sources as tools and loose objects.

Figure 13 shows the normal sound-absorption coefficient for the polyester-faced foam and the Mylar-wrapped fiberglass. Both sets of data were acquired by BBN using an impedance tube. The Mylar-wrapped fiberglass was used in the cab-mounted shields (R1 and L1) and the sound-absorptive package on the vertical assemblies (R4 and L4), as shown in Fig. 9 and listed in Table 2. The forward transmission cover (T1) and rear transmission cover also have the perforated plate, Mylar-wrapped packages installed on their undersides. Whenever possible, the treatment was kept above the frame rail, where one would expect to find

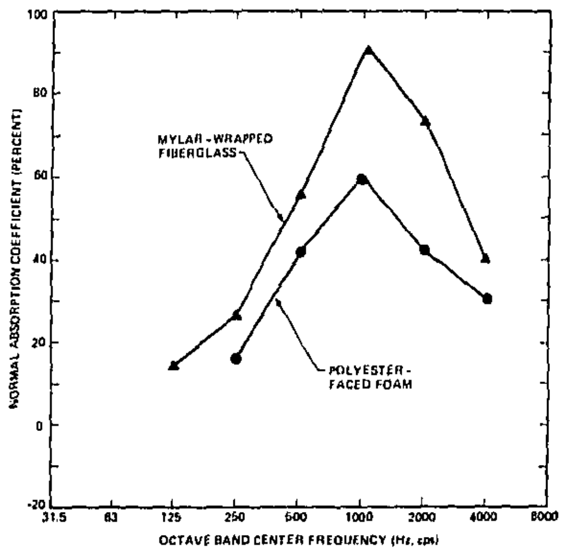

FIG. 13. NORMAL SOUND-ABSORPTION COEFFICIENTS FOR POLYESTER-FACED FOAM AND MYLAR-WRAPPED FIBERGLASS.

smaller amounts of oil, water, and grime. Vertical and top-horizontal orientations of treated panels were preferred over bottom horizontal orientations because of engine fluid leaks and grime buildup.

Side Shields and Shelves [R1, L1, and R2, L2].

The two side shields and two shelves (illustrated in Fig. 9) together enclose the area between the frame rails and the bottom of the cab. This Ford CLT 9000 is equipped with air ride suspension, which allows the cab to move vertically ±2 in. from the neutral position with respect to the frame rail. In addition, the cab is able to roll and pitch. The design goals for the shields and shelves were as follows:

- Keep side shields away from the engine to permit maximum air flow
- Provide large flat areas out of the way when cab is raised for maintenance accessibility
- Side shields should lift out of the way when cab is raised for maintenance accessibility
- The seal between the side shield and the shelf must allow for the vertical, roll, and pitch motion of the cab
- The shelves must be able to support the weight of a person.

Each cab-mounted side shield (L1, R1) is made of one straight sheet of 1/8-in. aluminum with cutouts to follow the contours of the bottom of the cab. The majority of the interior surfaces of the shields are covered with the Mylar-wrapped fiberglass construction illustrated in Fig. 12. The panels are attached to the cab with mounting brackets. Figure 14 shows the passenger side shield (R1) with the truck cab in the partially raised position. Transmission covers are also visible in the lower portion of the figure.

The shelves (R2, L2) are each fabricated from one piece of 0.160-in. aluminum. The heavier gauge material was used because of the weight supporting requirements of the shelves. The shelves start at the top of the frame rail, extend upward for about 5 in., and then turn 90° outward to meet the side shields. Several large support gussets brace each shelf. Figure 15 shows the details of the shelf and side shield assembly. Figure 16 is a photograph of two of the shelf support gussets. A 3-in.-wide strip of neoprene attached to the edge of the shelf forms a wiping seal for the gap between the edge of the shelf and the side shield.

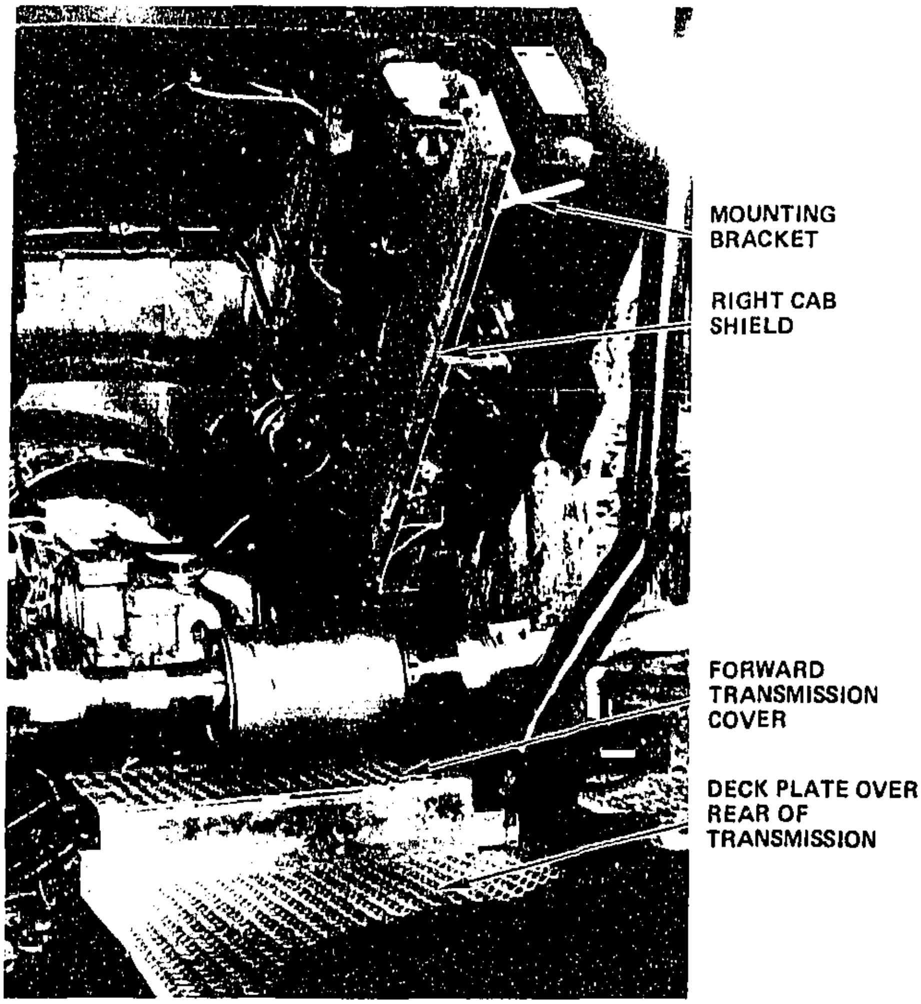

FIG. 14. REAR VIEW OF TRUCK WITH CAB IN PARTIALLY RAISED POSITION.

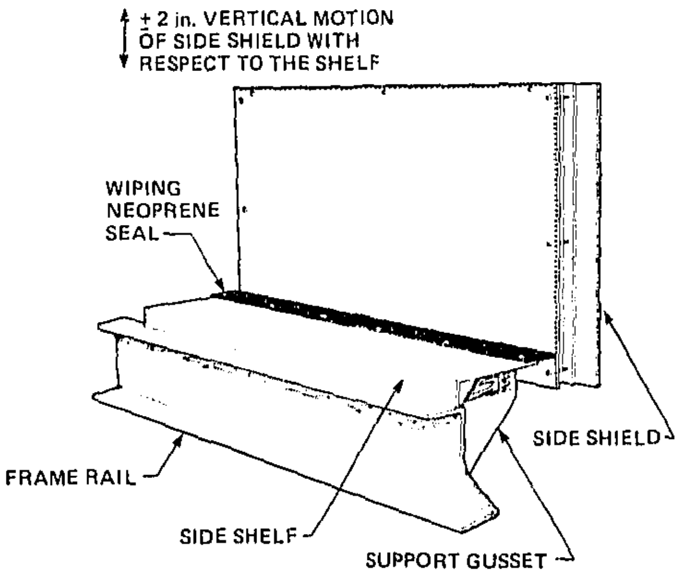

FIG. 15. CROSS SECTION DETAIL OF SHELF AND JUNCTION WITH SIDE SHIELD.

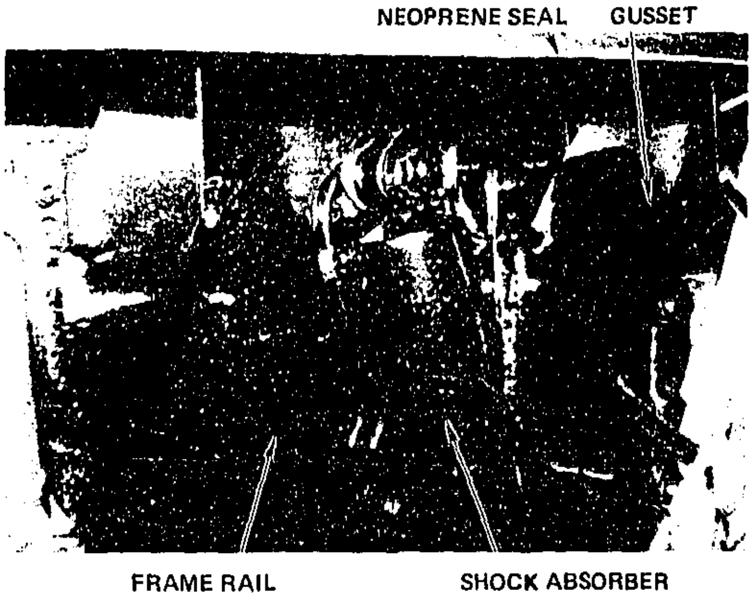

FIG. 16. TWO SHELF SUPPORT GUSSETS.

Bellypan [R3, L3, R4, L4, B1, B2, B3]

The bellypan encloses the bottom of engine, extending from the front bumper back to the rear of the transmission. The design goals for the bellypan are as follows:

- Maximum accessibility for maintenance purposes
- No reduction of ground clearance
- Quick and complete removal and replacement of bottom panels
- Provision for drainage
- Adequate clearance over front axle.

The two side panels of the bellypan (R3 and L3) are each made of one piece of 0.160-in. aluminum. The panels, which are attached to the frame rail with brackets, start at the bottom of the frame rail and extend vertically down. The two side panels are fastened together along the bottom by three narrow cross members. These cross members maintain the spacing between the two side panels when the bottom panels are removed, yet they cause minimal access restriction. Three removable bottom panels (B1, B2, and B3) enclose the bottom area between the side panels. The rear two panels are attached with quick-release fasteners (DZUS Model TL 802). Figure 17 shows two of the fasteners on the rear bottom panel. The front panel (B1) is attached with quarter-turn fasteners. The only sound-absorptive materials located below the frame rail are the two vertical panels at the rear of the bellypan (R4 and L4). These panels, seen in Fig. 18, provide absorption at the acoustically important rear end of the enclosure.

Walkplate and Forward Transmission Cover [T2 and T1].

The walkplate (T2) and the forward transmission cover (T1) enclose the top of the transmission. The only change to the walk

FIG. 17. TWO FASTENERS ON REAR BOTTOM PANEL.

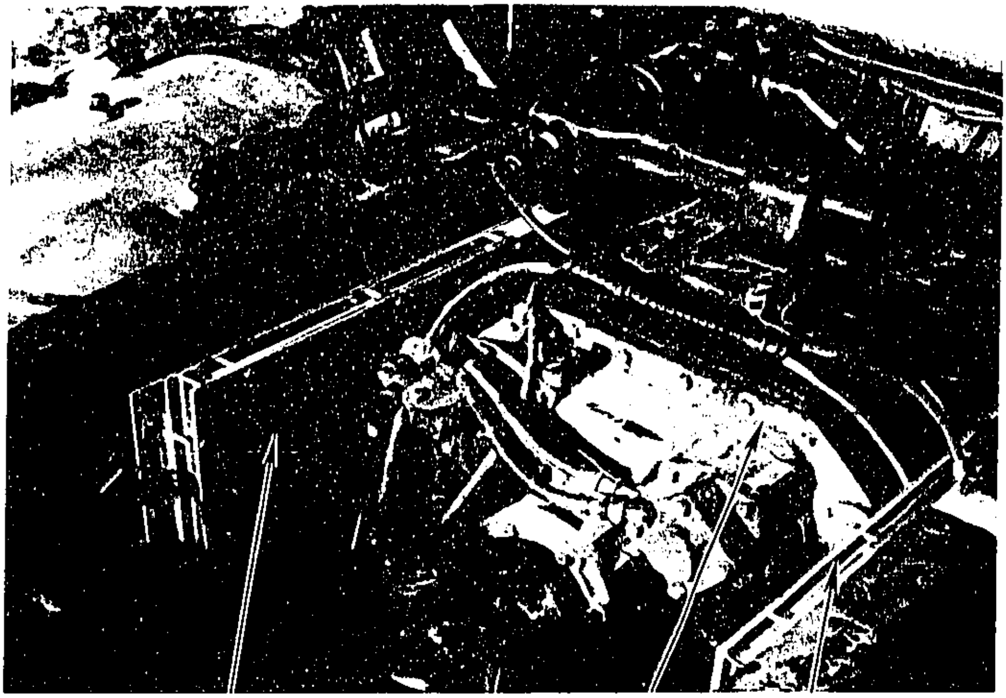

FIG. 18. TOP REAR VIEW OF SOUND-ABSORPTIVE PANELS WITH TRANSMISSION COVERS REMOVED.

plate, which is baseline equipment, is the addition of sound-absorptive treatment to the bottom side. The forward transmission cover rises about 6 in. to clear the transmission and extends forward of the walk plate. The bottom surface is also covered with sound-absorptive treatment. Both (T1 and T2) can be seen installed in Fig. 19.

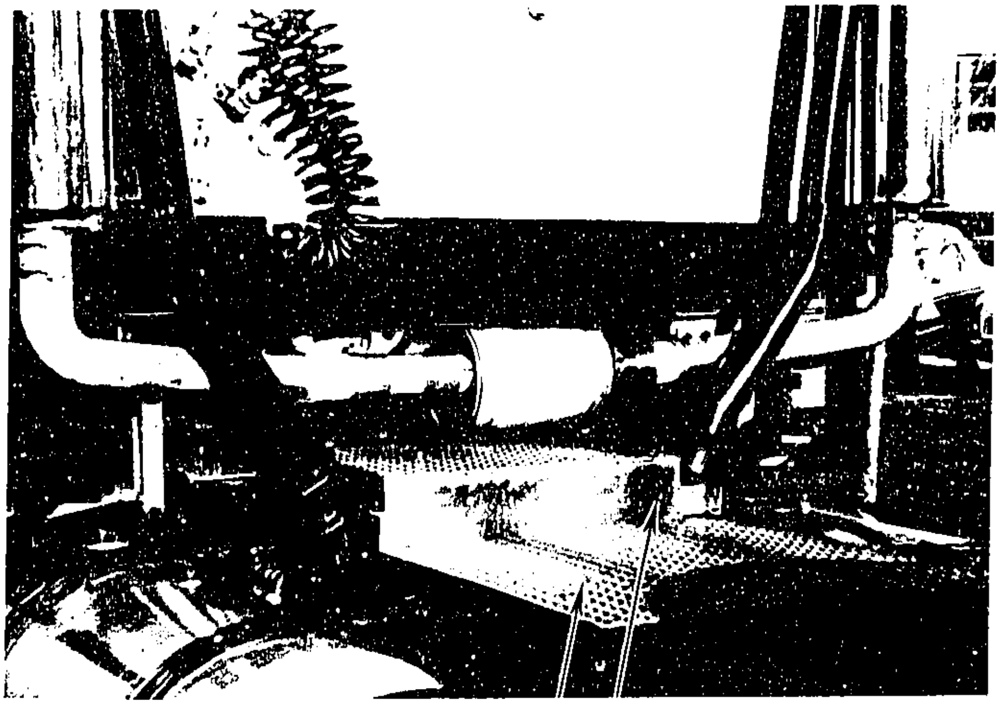

FIG. 19. REAR VIEW OF WALKPLATE AND FORWARD TRANSMISSION COVER.

The tunnel enclosure reduced the airborne contribution from the engine and transmission to the overall noise level by 4.7 dBA. The final contribution of the treated engine/transmission to the overall level was 71.5 dBA.

3.3 Suspension Modifications

The truck is equipped with a Rayco 101F Tandem rear suspension. During the acceleration test, the combination of the torque of the rear axle and the inputs from a slightly uneven road surface cause the spring assembly to slap against the mounting bracket and a spacer. This slapping occasionally causes unpredictable impulses in the passby data, as shown in Fig. 20. Fiber-reinforced 1/4-in. rubber sheeting was installed between the contacting surfaces to eliminate the noise. Figure 21 shows the installation on the right rear bracket.

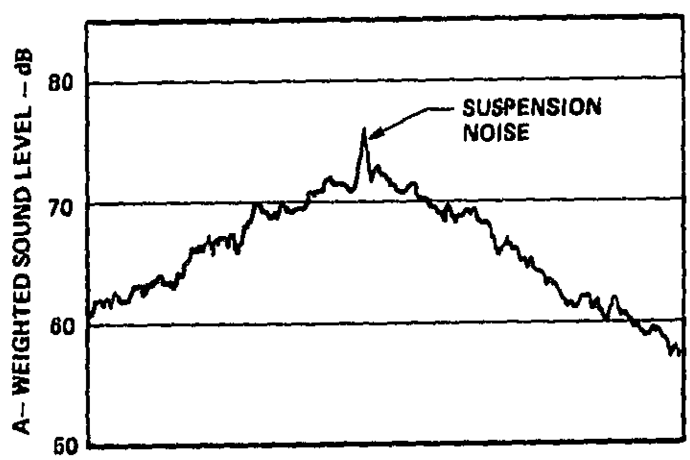

FIG. 20. ACCELERATION TEST PASSBY STRIP CHART.

FIG. 21. RUBBER SHEET INSTALLED ON REAR SPRING BRACKET.

4. FINAL NOISE LEVELS

Measurements of exterior and interior noise levels were conducted according to the procedures described in Appendix A of this report.

4.1 Exterior Noise Levels

Table 3 summarizes the noise source contributions for the initial and final vehicle configurations. The 4.8-dBA reduction in overall vehicle noise was achieved through a 4.7-dBA reduction in engine/transmission noise and a 9.5-dBA reduction in exhaust noise.

TABLE 3. SUMMARY OF NOISE SOURCE CONTRIBUTIONS.

Noise Source	Initial Level - dBA	Final Level - dBA	Noise Reduction - dBA
Engine/transmission	76.2	71.5	4.7
Exhaust	69.0	59.5	9.5
Intake	60.0	60.0	--
Other (Coastby)	60.0	60.0	--
Total	77.1	72.3	4.8

Exterior noise levels were measured by BBN in Cambridge, Massachusetts, on December 4, 1979 and by EPA in Sandusky, Ohio, on December 10, 1979. The results, shown in Table 4, are in close agreement with each other.

TABLE 4. FINAL EXTERIOR NOISE LEVELS.

	BBN Measurements Cambridge, MA			EPA Measurements Sandusky, OH		
	Run 1	Run 2	40 CFR 205 Level	Run 1	Run 2	40 CFR 205 Level
Left Side	72.1	71.9	72.3	72.6	71.7	72.6
Right Side	72.1	72.4		72.6.	72.6	

4.2 Interior Noise Levels

Figure 22 shows the SAE J336a criteria and the octave band interior noise levels measured before and after the application of noise treatment. The criteria band levels shown in the figure are those which are summed to establish an overall criterion against which actual levels are to be compared. The maximum allowable band levels, established by the SAE J336a Recommended Practice [9], are not to be exceeded if the vehicle is to meet the design criteria. The peak levels for the baseline and treated vehicle run about 8 to 20 dB below the maximum allowable levels. The A-weighted values for both configurations are within 0.2 dB of each other and about 9 dBA below the A-weighted value of the criteria band levels.

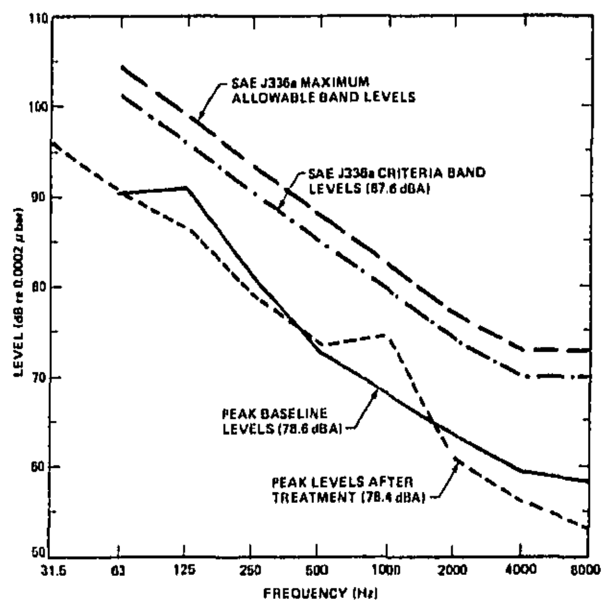

FIG. 22. INTERIOR NOISE LEVELS COMPARED WITH SAE J336a CRITERIA.

5. COOLING PERFORMANCE

Cooling tests were conducted in a wind tunnel operated by the Modine Manufacturing Co. and illustrated in Fig. 23. During a test, air is introduced by a blower in front of the truck and is maintained at a constant speed and temperature, and the truck runs on a chassis dynamometer with heavy cables positioning both sets of the tandem rear wheels on the dynamometer rollers. Exhaust gases from both stacks are piped to the outside of the facility.

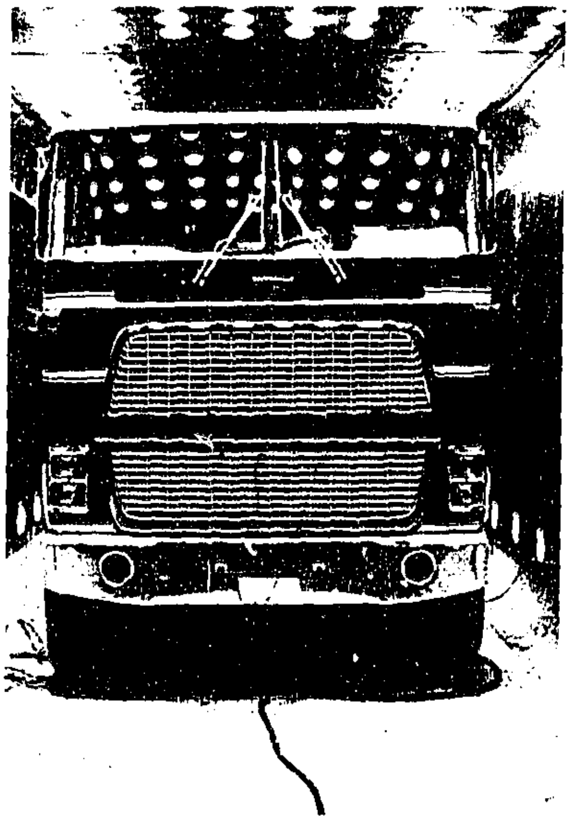

FIG. 23. TRUCK IN WIND TUNNEL.

The primary purpose of the test is to evaluate engine cooling system performance, which is measured by the Air-to-Boil (ATB) temperature, the estimated ambient air temperature at which the coolant would reach 212°. That is,

$$ATB = 212 - T_1 + T_a \, , \qquad (1)$$

where T_1 = coolant temperature measured at the radiator inlet
T_a = measured ambient temperature.

Although pure water at standard pressure boils at this temperature, truck coolants operating under pressure boil at a higher temperature. Accordingly, vehicles that meet this worst-case test are very unlikely to encounter cooling problems under service conditions.

The truck was fully instrumented to measure temperatures at key locations. The vehicle was run out on a chassis dynamometer to simulate driving and to control output power. Tests were performed at three major operating conditions with the engine at maximum power, idle, and peak torque. Ambient air temperatures were held at a nominal 100°F, and air speeds ranged from 0 to 44 mph.

The results of these tests are shown in Table 5. Probably the most critical test was the Air-to-Boil (ATB) at max power. The vehicle passed this test by 1.1°F. Engine oil temperatures were always below the 235°F specification established by the Caterpillar Tractor Co. Engine oil reached its highest temperature of 224.2°F during the max power, low airspeed test.

The transmission oil temperatures were also always below the 250°F value specified by the Eaton Corp. for extended operating intervals. Somewhat surprisingly, the maximum value was reached during the idle test, when the fan was running at only 744 rpm

TABLE 5. RESULTS OF CLT 9000 WIND TUNNEL TESTS

Operating Condition		Max Power	Idle	Peak Torque	Max Power	Max Power
Air Speed (mph)		14.0	0	14.4	26.7	44.0
Air Temp. (°F)		101	96.8	100.2	100.8	100.1
Engine Speed (rpm)		2000	650	1500	2000	2000
Fan Speed (rpm)		2095	744	1636	2109	2107
ATB (°F)	Meas.	113.1	131.8	104.7	123.0	125.4
	Ford Spec	112	-	-	-	-
Engine Oil Temp. (°F)	Meas.	224.2	190.4	224.1	217.0	213.8
	Cat. Spec.	235	235	235	235	235
Transmission Oil Temp. (°F)	Meas.	214.8	225.0	212.8	206.9	179.3
	Eaton Spec	250	250	250	250	250
Cab Temps (°F) (A/C On)	Above Pedal	75.0	78.6	74.9	75.7	83.8
	Above Seat	75.4	78.8	75.0	75.6	80.7
	Cab Center	75.4	79.0	75.0	75.5	80.6

and the transmission was in neutral. This test immediately followed the max power test, which had been running sufficiently long to reach steady temperature. As shown by the lower curve in Fig. 24, when the engine load was reduced and the speed lowered, the temperature of the air from the fan (i.e., the fan blast) increased by about 13°F. This increased air temperature, decreased air velocity, and thermal gradients in the transmission allowed the transmission oil temperature to rise about 7°F before beginning a long decline.

Since the cab temperature was of concern, measurements were made at locations above the accelerator pedal, above the driver's seat, and at the approximate center of the cab above the dog house. The data presented in Table 5 show that the air conditioner held the temperatures at all three measurement points to 75° to 79°F, except for the last run shown, during which temperatures ranged from 80° to 84°F. Subsequently, the air conditioner became inoperative; it may not have been functioning properly during this last test.

In summary, the truck met its noise and cooling objectives and was judged ready to be evaluated for field service.

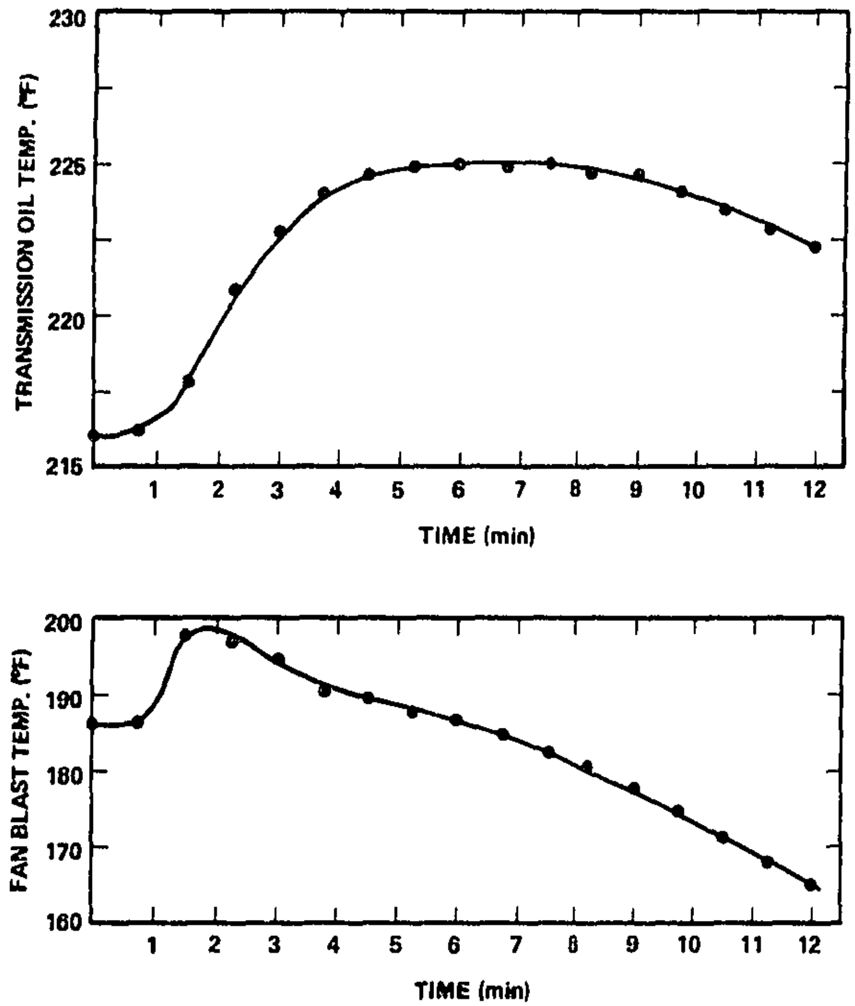

FIG. 24. TRANSMISSION OIL AND FAN BLAST TEMPERATURES. (ENGINE LOAD WAS ELIMINATED DURING THE FIRST MINUTE.)

6. COST ESTIMATES

This section discusses the costs of the noise control treatments described in previous sections. There is a specific cost attributable to the manufacture and installation of each major noise control treatment: the engine/transmission enclosure, and the exhaust system. We first present a summary of these costs and then discuss the estimation of each cost element. The cost of operating the vehicle, as affected by changes in fuel consumption, available payload, and maintenance, is also important and will be treated in a separate report covering the in-service test program.

Table 6 presents the distinctions between cost and price used in this report. The convention is that the seller sells at a price, and the buyer buys at a cost. There are three sellers: the manufacturer of noise control products (e.g., a muffler manufacturer), the truck manufacturer, and the truck dealer. The three buyers are the truck manufacturer, the truck dealer, and the truck operator. A markup is applied in moving from one level to another. Hence,

manufacturer's price x dealer's markup = dealer's price.

TABLE 6. SUMMARY OF COSTS AND PRICES.

Transaction	Cost	Price
Sale of Component Supplier's Parts to Truck Manufacturer	Manufacturer Cost	Supplier Price
Sale of Truck by Manufacturer to Dealer	Dealer Cost	Manufacturer Price
Sale of Truck by Dealer to Operator/Customer	Operator Cost	Dealer Price

There is no single, generalized approach for cost estimation. The costing and pricing procedures of each truck manufacturer are highly confidential for reasons related to competition.

Our approach to costing has been to rely on several different procedures, with the use of each determined by the item to be costed and the information available. In some instances we have used two different procedures to establish an upper and lower bound for the cost of a treatment. Reliance has been placed on information and relationships derived in Refs. 10 and 11. All costs are in 1979 dollars.*

6.1 Summary

Table 7 presents an overall summary of the treatment weights. Table 8 presents a summary of the estimated overall cost and price increases attributable to the noise control treatments installed on the Ford CLT 9000. The weight of the truck increased by 397 lb, approximately 2-1/2% of tractor tare weight, or 1/2% of the 80,000-lb maximum permissible gross combination weight. The estimated price increase of $1309 is a 2.7% increase over the $48,000 purchase price of a truck tractor. The correspondence between the percentage weight gain and percentage price increase is reflective of the weight-based approach used in developing the price estimates for the enclosure treatment.

TABLE 7. SUMMARY OF TREATMENT WEIGHTS.

Treatment	Weight (lb)	Net Increase (lb)
Engine-Transmission Enclosure		221
Components added	241	
Components removed	<20>	
Exhaust System Modifications		176
Components installed	248	
Components removed	<72>	
Total Weight	397	397

*Costs and prices are in 1979 dollars for consistency among reports in this series.

TABLE 8. SUMMARY OF COST AND PRICE INCREASES.

Treatment Costs	Estimated Cost	Increase Price
• Enclosure	$627	$ 940
• Removal-Transmission Cover	<40>	<60>
• Exhaust System	318	429
Total Increase	$905	$1309

The cost and price estimates presented here are BBN estimates for the retrofit treatments developed by BBN. They are not necessarily identical to the cost and price of a comparable enclosure, were it to be installed by a truck manufacturer on production line vehicles. There are reasons why BBN cost estimates could differ from actual manufacturer costs. The BBN enclosure design is essentially a retrofit. More cost-effective design and materials specification by a manufacturer for actual production vehicles might well result in different enclosure specifications and per-vehicle costs. While BBN has accounted for research, development, and testing (RD&T) and tooling costs by adjusting manufacturing cost estimates upward, that adjustment could be inaccurate, particularly if tooling or RD&T costs were atypical. The markup factors for manufacturers could differ among manufacturers from the markups assumed by BBN. Accordingly, the cost and price estimates presented here should be viewed as representative estimates for the treatments installed on the truck.

6.2 Enclosure Costs

Approach

The primary method of estimating the cost of the enclosure installed on the Ford CLT 9000 was to examine the relationship between the weight of materials and the cost of materials. This is a commmon technique used in industrial engineering. Some components, such as special machined parts and electronic devices, have a price per pound greater than the overall price per pound of the truck; others are clearly less. Our focus was on the weight-cost relationship for an enclosure, and the first step was to obtain data with which to estimate a relationship. Having established a relationship, we could then estimate the cost of the enclosure for the Ford, given the weight of the enclosure.

Fax and Kaye [10] present data on the weights and associated costs for eight alternative enclosure designs for the Freightliner Quiet Truck. We reviewed that information and inflated those 1973 cost estimates to 1979 dollars, using the Producer Price Index for nonferrous metals for both years. This price index was used because the enclosure is primarily made of aluminum. The 1973 value of the index was 135.0. The midyear (July) 1979 value of the index was 262.3, for an increase of 94% over the six years.

A plot of the eight observations with manufacturer's price in 1979 dollars is presented in Fig. 25. A least squares regression derived from the data is also shown as the dashed line on the figure. The estimated equation is:

$$Y = 61.3 + 1.92X \quad R^2 = 0.99, \qquad (2)$$
$$\quad (33.3)\ (0.09)$$

where Y = manufacturer's price in 1979 dollars

X = enclosure weight in pounds.

The coefficient of determination, designated as R2, can be interpreted as the variation in the dependent variable (manufacturer's price) accounted for by variation in the independent variable (enclosure weight). In this instance, 99% of manufacturer's price can be "explained" by enclosure weight. The terms listed in parentheses under the equation are the standard errors for each term. The estimated slope coefficient indicates that a 1-lb increase in weight would result in approximately a $1.92 increase in manufacturer's price (or a $2.88 increase in dealer price).

This equation shows only the relationship between weight and price of a prototype enclosure. It does not include any costs for special tooling or research, development, and testing associated

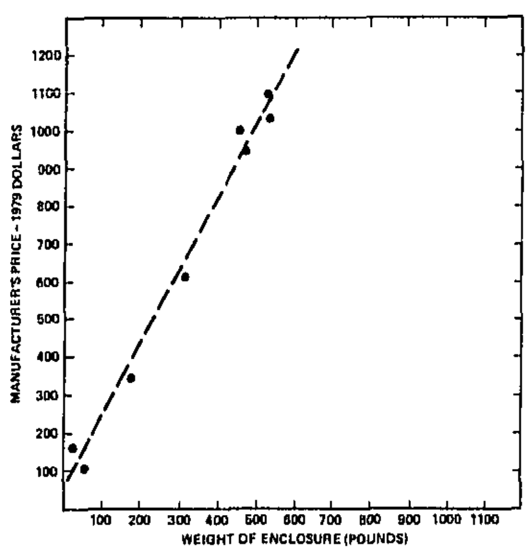

FIG. 25. RELATIONSHIP BETWEEN ENCLOSURE WEIGHT AND MANUFACTURER'S PRICE.

with commercial production of the enclosure. Accordingly, any cost or price estimate derived from this equation is downward biased, since it excludes these costs. Conversely, it does not reflect any cost savings attributable to production economies.

Estimated Enclosure Costs

A summary of materials and weights for each section of the enclosure is presented in Table 9. As indicated from the entries in the table, aluminum is the predominant material, accounting for approximately three-quarters of the total weight of the enclosure. The information presented in Table 8 is based upon Tech Weld's bill of materials and from dimensional measurements made by BBN. The weight of the enclosure is partially offset by the removal of the original transmission covers, which, according to Ford, weigh 20 lb. Thus, the net weight of the enclosure is approximately 221 lb. In developing the cost estimates for the BBN enclosure, we have considered the gross weight of the enclosure, 241 lb. The cost and price of the transmission covers that were removed are estimated separately and then deducted from the gross weight and gross estimates.

Given the enclosed weight of 241 lb and weight-cost relationship, expressed in Eq. (1), the estimated manufacturer's price of the enclosure is $524. Following the markup practice reported by Fax and Kaye [10] p. 78, we assume that a markup of 1.5 is applied to manufacturer's price to obtain an estimated price of $787. Note, however, that this is a lower bound, since it excludes tooling and RD&T costs.

To obtain an upper-bound cost that would account for tooling and RD&T costs, we reviewed the estimated price increase attributable to enclosures in the Medium and Heavy Truck Background Document [11]. The Background Document presents an estimated purchase price increase of $625 in 1973 dollars for a comparable enclosure design [11], pp. 6-4, 6-5. This price does include development and testing costs. If the 1973 price is inflated to 1979 prices using the producer price index for transportation equipment, the 1979 price would be $1020.

TABLE 9. SUMMARY OF ENCLOSURE MATERIALS AND WEIGHTS (LB).

Treat. Code	Component	0.125 Alum.	0.16 Alum.	#16 Ga. Perf. Alum.	Alum. Channel Spacer	0.25 Alum. Plate	"703" 1 ½ in. Fiber.	Mountings, Brackets etc.	Total Weight
R1, L1	Upper Side Panel (2)	33.88		5.80	8.30		5.42	6.26	50.66
R2, L2	Upper Side Shelf (2)		21.34					29.03	50.37
R3, L3	Lower Side Panel (2)		24.90					10.03	35.20
R4, L4	Sound Absorption Package (2)	8.45		1.72	3.84		1.51		15.52
B1	Forward Bottom Panel	12.94							12.94
B2	Middle Bottom Panel	6.59							6.59
B3	Rear Bottom Panel	20.87							20.87
	Stiffeners	1.98						2.52	4.50
T1	Forward Transmission Cover		8.63	0.82	1.91	15.65	0.71	0.47	28.19
T2	Rear Transmission Deck Plate			2.15	2.74		2.03		6.92
	Total Weight	84.71	54.87	10.49	16.79	15.65	9.67	48.58	240.76*

*Excludes screws, springs, nuts, bolts, latches, mylar, plastic netting.

Given these upper and lower bounds, of $787 and $1020, BBN estimates that the actual price of the enclosure would be approximately $940. This estimate is based upon the $787 estimate (rounded up to $790) plus an allowance for tooling and RD&T expenses of $150. Given variations in a manufacturer's nonmaterial cost, the price increase could range between $900 and $1000. We believe $940 is a reasonable estimate, since it is based upon a statistically significant relationship between cost and weight and allows for adequate coverage of tooling and RD&T costs.

The cost of the BBN enclosure is partially offset by the removal of the transmission covers that were originally on the truck. BBN estimates the cost of the cover to be approximately $40, or $2 per lb, and the price of the covers to be $60.

The net estimated cost of the enclosure is therefore $587; the net estimated price is $880. The latter represents a 1.8% increase in the purchase price of the truck.

6.3 Exhaust System Costs

The components in the final exhaust system and their respective weights are presented in Table 10. The weight increase of 176 lb is the incremental weight increase of our dual exhaust system over the standard single vertical muffler system. While a single vertical muffler and pipe is standard on the Ford CLT 9000, an optional dual vertical muffler exhaust system is available for the Caterpillar 3406 engine. The cost (wholesale delivered) of the optional dual muffler system is $257.50, while the suggested retail price is $348.61, or a final markup of 1.354. Our approach to estimating the costs of the final exhaust system was to estimate the incremental costs and prices of our

TABLE 10. SUMMARY OF EXHAUST SYSTEM COMPONENTS AND WEIGHTS.

Component	Weight (lb)
Installed	
Mast and Mounting Bracket	46.0
Mufflers (2)	122.5
Tee Can	20.0
Piping	24.0
Seals and Clamps	15.7
Stack Silencers	20.0
Removed	
Original muffler	<62.25>
Original Stack	<10.00>
Net Increase	175.95

treatments applied to the optional dual vertical muffler exhaust system, for which the cost of $257.50 was known.

Two basic changes to the optional dual muffler system were made that would increase the price. First, the "wye" pipe connection, which splits the exhaust into two pipes, was replaced by a Splitter Tee Can. Second, Super Stack silencers were installed on the mufflers in place of straight exhaust pipes. We also installed new mufflers, but they are comparable in cost to the mufflers that would be installed as part of the optional dual muffler package.

The BBN exhaust component treatments were manufactured by Donaldson. OEM prices were supplied to BBN to be used only for "computational purposes" in order to derive total costs, without revealing the costs of individual components. The OEM prices are, in effect, the price the truck manufacturer would pay for a component. A markup is subsequently applied to an OEM price to obtain manufacturer's cost. BBN estimates that markup to be 1.4

for the components in the optional dual muffler system and the $257.50 cost of that system. This estimate assumes the cost of the mast and bracket to be $92, or $2 per pound.

The costs and prices of alternative exhaust systems are summarized in Table 11. The incremental increase in truck cost attributable to the components installed by BBN over the optional dual vertical muffler system is estimated to be approximately $60. Therefore, the total cost of the BBN exhaust system is $317.50 more than the standard single muffler system. The estimated price of the final exhaust system is $429 more than the standard single muffler system, or $80 more than the optional dual exhaust system.

TABLE 11. SUMMARY OF INCREMENTAL COST AND PRICE INCREASES FOR EXHAUST SYSTEM OPTIONS.

Exhaust System	Increase from Base	
	Dealer Cost	Dealer Price
Standard single muffler	base	base
Ford dual mufflers	257.50	348.61
BBN dual mufflers	317.50	429.00
BBN dual mufflers with aluminized finish	242.49	327.36

The price estimate of $429 should be regarded as a high-side estimate, since truck purchasers seldom pay suggested retail list price. A more general practice is to negotiate some dollar amount over wholesale delivered cost. Accordingly, the actual price a truck purchaser would pay for the BBN dual exhaust system ranges between $317.50 and $429.

The mufflers and stack silencers used on the Ford CLT 9000 have a bright finish. There is a premium at the OEM price level for this chromelike finish in comparison to a duller aluminized finish. BBN opted for the shiny finish for the sake of appearance. Accordingly, the price of the BBN treatments could be reduced by the substitution of aluminized for bright stainless components. The aluminized-finish version of the BBN system is estimated to cost $242 and have a price of $327.

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APPENDIX A: NOISE TEST PROCEDURES

Three procedures have been followed in testing the truck for noise and cooling performance. Exterior noise is measured according to the procedure described in 40 CFR 205, which is very similar to the SAE J366b Recommended Practice. Interior noise is measured according to the SAE J336a Recommended Practice. Cooling tests are performed according to a procedure established by the Ford Motor Co. These test procedures are described in considerable detail in documents which should be consulted by readers who wish to understand them fully (see Refs. 7 and 9 in main report). Here we describe the major features of each noise test.

Exterior Test (40 CFR 205)

The exterior test is a low-speed full-throttle acceleration test intended to characterize drive train noise while deemphasizing tire and aerodynamic noise [7]. The general arrangement of the test site is illustrated in Figure A.1. The site includes a paved vehicle path and measurement area, surrounded by an area that is free of reflecting objects. A microphone is located 4 ft above the ground and 50 ft from the center of the vehicle path. During a test, the vehicle is driven along a straight path at a constant speed corresponding approximately to two-thirds of governed engine speed. At the acceleration point, the throttle is opened fully. The vehicle accelerates through the next 100 ft, reaching maximum governed rpm in the test zone. The truck is operated in the highest gear step that will permit it to meet this requirement. The peak noise level is generally measured twice on each side, and the highest of the average values for each side is reported. Precision sound measuring equipment is used to ensure that accurate data are acquired.

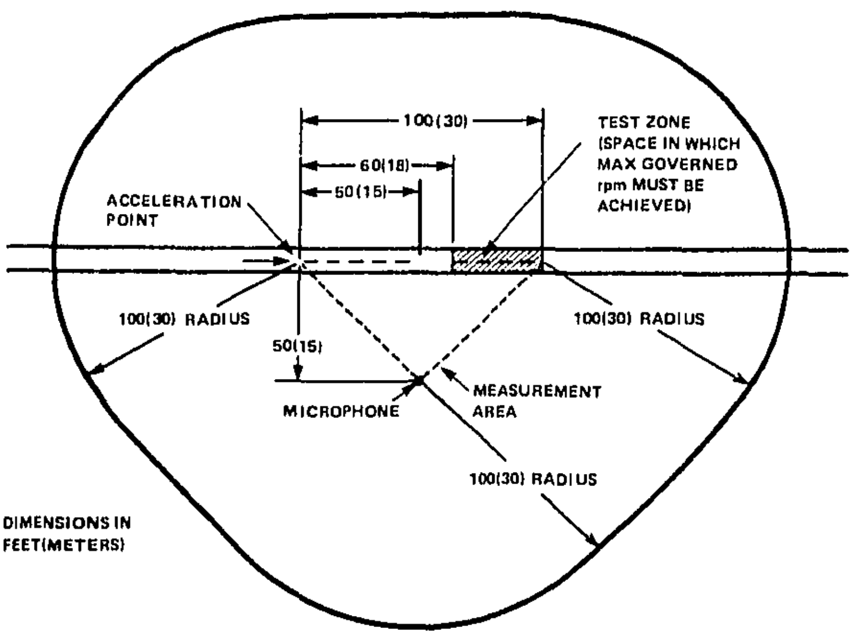

FIG. A.1. TEST SITE FOR EXTERIOR NOISE LEVEL MEASUREMENTS.

For the noise data reported here, the following operating conditions apply:

Engine Speed	- approach:	1000 rpm*
	- final:	2250 rpm
Vehicle Speed	- approach:	9 rpm
	- final:	21 rpm
Gear Step:		4th*

*The gear step and approach engine speed were determined experimentally as required by the test procedure. It was found that when the truck approached in fifth gear, with the engine running at two-thirds of governed speed, the engine reached governed speed when the vehicle was beyond the test zone. In fourth gear and at two-thirds of governed speed, the engine reached governed speed before the test zone. Accordingly, the engine speed at approach was reduced by a 100-rpm increment until it was found

An important feature of this test procedure is that it allows thermostatically controlled radiator fans to remain inoperative. Accordingly, the thermostat on the fan was disengaged by removing a small piston, thus permitting the fan to turn only at a low speed, at which its noise contribution was judged inconsequential.

Interior Test (SAE J336a)

The SAE J336a Recommended Practice specifies noise measurements 6 in. from the driver's ear while the truck is accelerating at full throttle from approximately 25 mph to 50 mph [9]. The gear step is selected so that the engine reaches rated speed at 50 mph. The test is performed with windows and vents closed and accessories turned off. Because of the relatively high speed at which the test is conducted, one may expect tire noise to be a more significant part of the total measured level than in the case of the 40 CFR 205 or SAE J366b test procedures.

The SAE J336a test procedure does not require the reporting of the A-weighted level, but rather the average of the two highest levels in each octave frequency band. Table A.1 illustrates the band center frequencies for which measurements are to be acquired and the band pressure levels to be considered during the development of new vehicles.

TABLE A.1. BAND CENTER FREQUENCIES AND BAND PRESSURE LEVELS.

Octave Band Center Frequency, Hz	Band Pressure Level, dB	Octave Band Center Frequency, Hz	Band Pressure Level, dB
63	101.5	1000	79.5
125	96.0	2000	74.0
250	90.5	4000	70.0
500	85.0	8000	70.0

The Recommended Practice states that "Trucks meet the design criteria if the sum of reported band pressure levels does not exceed the sum of the criteria band pressure levels, provided that no reported band pressure level exceeds the corresponding criteria band level by more than 3 dB." While the Recommended Practice does not specify an A-weighted criterion, the (logarithmic) sum of the A-weighted values of the band pressure levels specified in the above table is 87.6 dBA.

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