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Noise Reduction Technology and Costs for a General Motors Brigadier Heavy-Duty Diesel Truck

Environmental Protection Agency

October 1981

Demonstration Truck Program

3

DISCLAIMER CLAUSE

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 General Motors Brigadier heavy-duty diesel truck from 81.7 to 71.6 dBA. The noise control treatment consists primarily of a dual exhaust silencing system and a partial enclosure for the engine and transmission. The noise treatment increases vehicle weight by 340 lb and estimated vehicle price by $1174. Wind tunnel tests on the completed truck show that temperatures of engine coolant and oil remain within manufacturer's specified limits.

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NOISE REDUCTION TECHNOLOGY AND COSTS FOR A GENERAL MOTORS BRIGADIER 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 General Motors (GMC) Brigadier truck tractor, 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, and therefore 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 treatments were 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 versions 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 costs reports. For example, a reader who has already read one report will 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 General Motors Corporation provided technical information and conducted cooling tests on the treated truck. The Donaldson Company supplied the exhaust silencing system, and Tech Weld fabricated the engine enclosure components. Noise testing was done at Hanscom Field with the cooperation of the Charles Stark Draper Laboratories and the Massachusetts Port Authority.

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1. INTRODUCTION

The primary objective of the project described in this report has been to reduce the noise level of a General Motors Brigadier heavy-duty diesel truck from 81.7 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, is 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 in a normal manner. 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 will be treated here; operating costs will be determined during the course of a subsequent in-service evaluation.

The technical approach to the development of noise treatment for the GM Brigadier has involved four major phases:

I. Baseline noise testing
II. Development of noise control treatments
III. Final noise and cooling tests
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 we conduct exterior noise measurements. Diagnostic tests are also performed to determine contributions from major noise sources (intake, exhaust, tires, engine, and transmission). Quantitative goals for each source are established and compared to the actual 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 mockup, built of 1/4-in. Masonite and fiberglass, is tailored to the vehicle. These inexpensive and easy-to-form materials are used because of the cut-and-fit approach that is needed to conform to the complex geometry associated with the truck and its many components.

After a suitable mockup 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 to tune the system acoustically, thereby bringing the vehicle into closer compliance with the goals.

In Phase III, the truck undergoes final noise testing, again 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.*

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

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, and the cooling performance is discussed in Sec. 5. The incremental costs and purchase price associated with the noise treatment are estimated in Sec. 6. Noise test procedures are briefly summarized in Appendix A.

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 Brigadier Model J9C064 short conventional 6 x 4 tractor with a 146-in. wheel base. The cab has a 92 3/4-in. length (BBC). Fully fueled, but without a driver, the tractor weighs 16,100 lb; it has a gross combination weight rating (GCWR) of 80,000 lb.

Figure 1 shows that the baseline truck is equipped with a single vertical exhaust system. The exhaust piping consists of

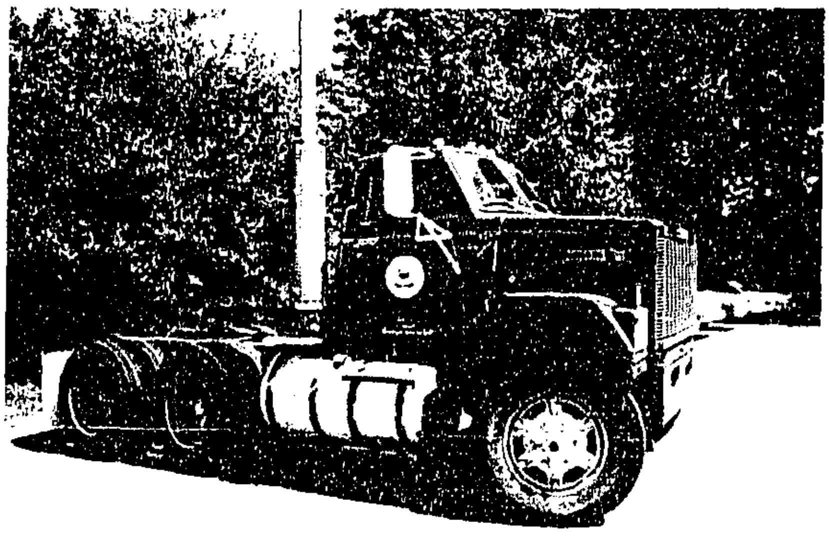

FIG. 1. BASELINE TRUCK CONFIGURATION.

sections of 5-in.-diameter stainless steel flex hose and aluminized steel tubing. The exhaust muffler, Donaldson Model WKM10-0105, has a nominal 10-in.-diameter double body and a standard 44 1/2-in. body length.

The engine, part of which is visible in Fig. 2, is a Detroit Diesel Allison Model 6V92TT diesel. It is a two-stroke-cycle V-6 direct injection engine equipped with a turbocharger. The engine has a 552-cu-in. (9-L) displacement and is rated at 270 hp at 1950 rpm.

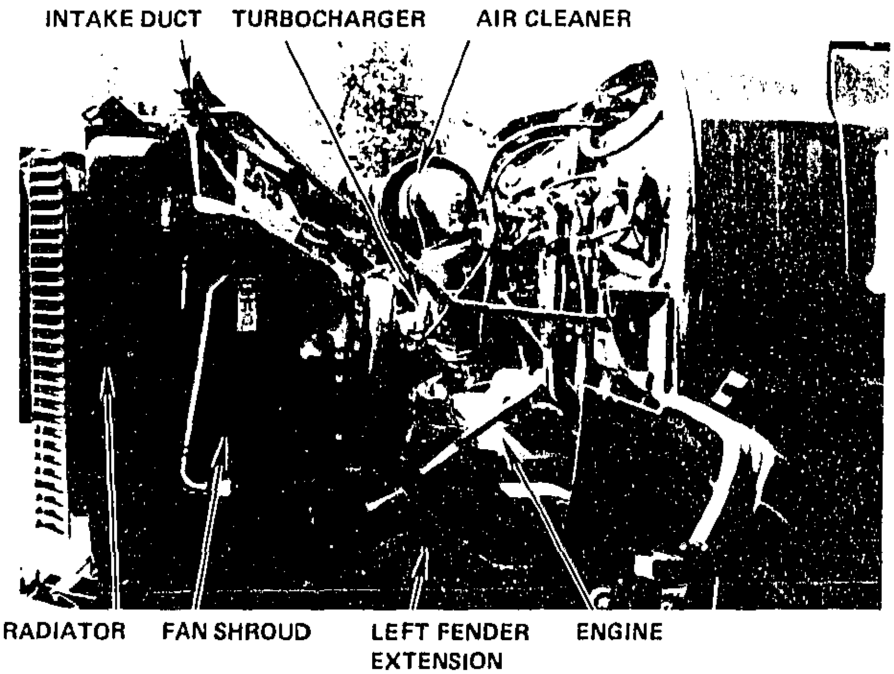

FIG. 2. LEFT SIDE OF TRUCK SHOWING MAJOR UNDERHOOD COMPONENTS.

Engine intake air enters through a duct at the front of the truck just above the radiator and passes through an 11-in.-diameter Donaldson Model ECG11-2002 air cleaner. The air then enters the turbocharger, where it is compressed before entering a blower.

As Figs. 1 and 2 show, the short length of this truck results in a densely packed space under the hood. We anticipated that the addition of an enclosure would significantly curtail the flow of radiator cooling air, possibly resulting in inadequate cooling. As a precautionary measure, General Motors, at BBN's request, replaced the original radiator with a larger one. Both radiators have the same construction, with a depth of 2.88 in. and 13 fins/ in. However, the larger radiator has a 1405-sq-in. frontal area (44 x 32 in.), as contrasted with a 1235-sq-in. frontal area (44 x 28 in.) for the original radiator.

The 32-in.-diameter cooling fan has eight evenly spaced stamped sheet metal blades and is thermostatically controlled. The thermostat is located at the coolant outlet from the engine. When the engine is cool, the fan idles at a low speed. When the coolant temperature reaches 190° to 192°F, the thermostat positions a valve, which supplies engine oil to the fan drive. The fan speed then increases to about 87% of engine speed.

The transmission and rear axles are manufactured by the Eaton Corp. The transmission, a Fuller (division of Eaton) Model RT-9509A, has nine forward speeds. The Model DS-340 tandem drive rear axles have a 4.11 speed ratio.

All wheels were equipped with Goodyear Unisteel II 11 x 24.5 radial tires with ribbed tread patterns. These tires were selected for their noise levels, which are lower than those with the crossbar tread commonly used on tractor drive axles.

On the baseline truck, engine noise is controlled primarily by an underhood sound-absorptive treatment, inner fenders, and fender extensions. The left fender extension is visible in Fig. 2 at the lower center of the photograph. Figure 3 shows the right fender extension and the underhood material. Figure 4 shows the right inner fender and its position with respect to the fender extension. The underhood material is 1-in.-thick fiberglass coated with polyvinyl chloride to prevent flaking.

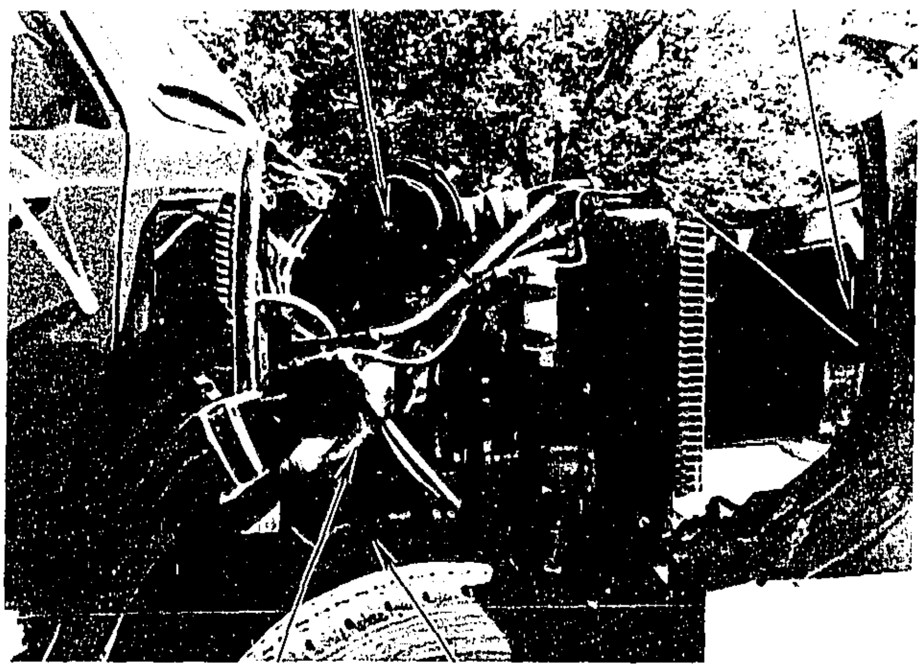

FIG. 3. RIGHT SIDE OF TRUCK SHOWING MAJOR NOISE CONTROL COMPONENTS.

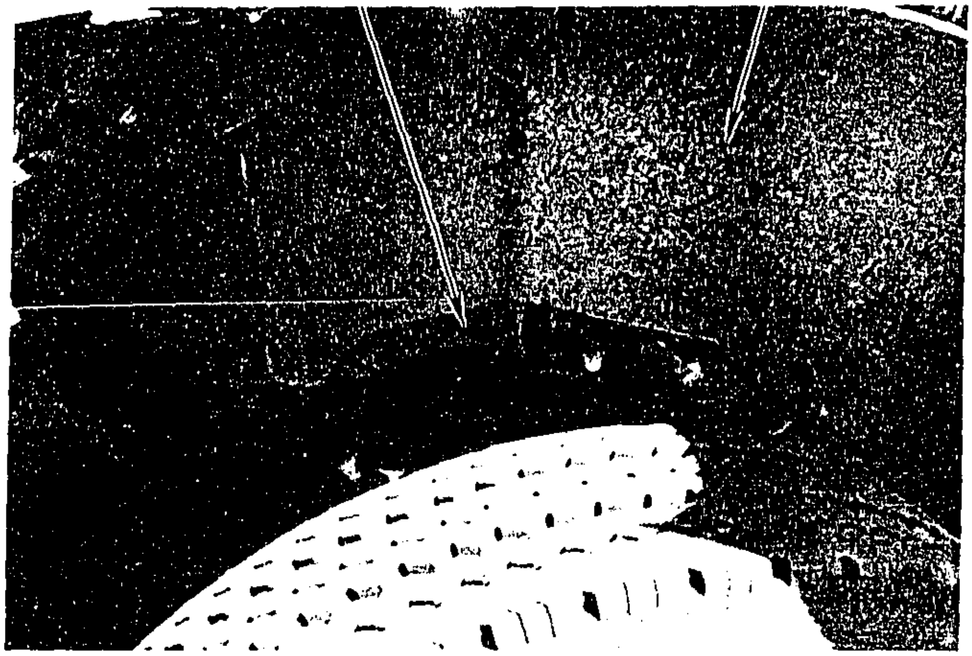

FIG. 4. RIGHT INNER FENDER AND FENDER EXTENSION.

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 [6]. 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 10 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 81.7 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	80.6	81.5
Right Side	80.9	81.7

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 treatment, 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. 5. The laboratory consists 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 an interior concrete wall and an exterior foam surface. The concrete is sufficiently thick to attenuate noise radiated by the engine to negligibly low levels. The sound-absorbing foam is intended to minimize the contribution of intake noise that is reflected from the concrete wall. The ECG11-2002 air cleaner and frontal air intake duct used in the test are the same models as those installed in the Brigadier. A barrier was placed, as shown in Fig. 5, to simulate the effect of the cab on the radiated sound field.

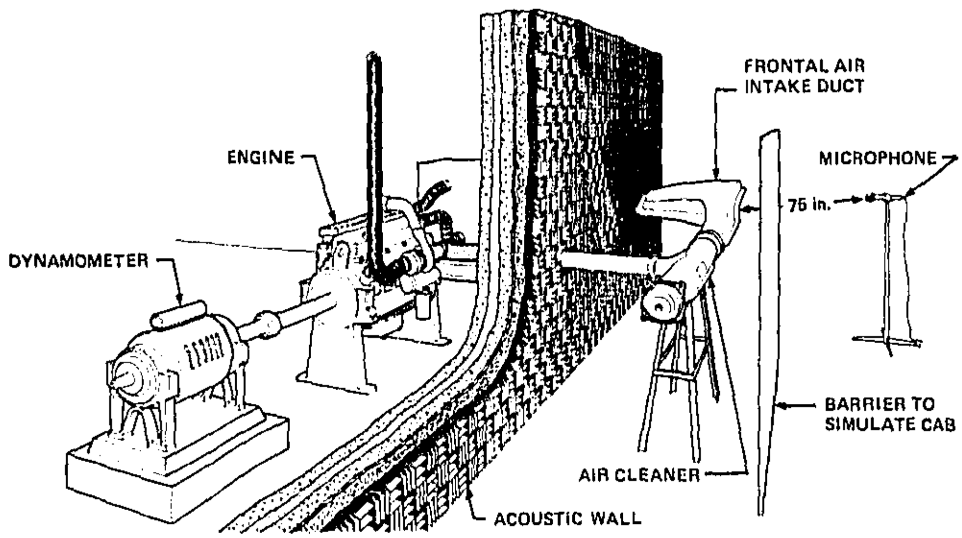

FIG. 5. EXPERIMENTAL CONFIGURATION FOR INTAKE NOISE MEASUREMENT.

Because intake noise levels were relatively low, a microphone was placed 75 in. from the intake duct so that an adequate 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 69.5 dBA, which, when 18 dBA are subtracted, extrapolates to 51.5 dBA at 50 ft.

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 noise level. We estimated the contribution from these sources by conducting coastby tests, which provide particularly good indications of tire and aerodynamic noise. Figure 6 shows the data plotted on a

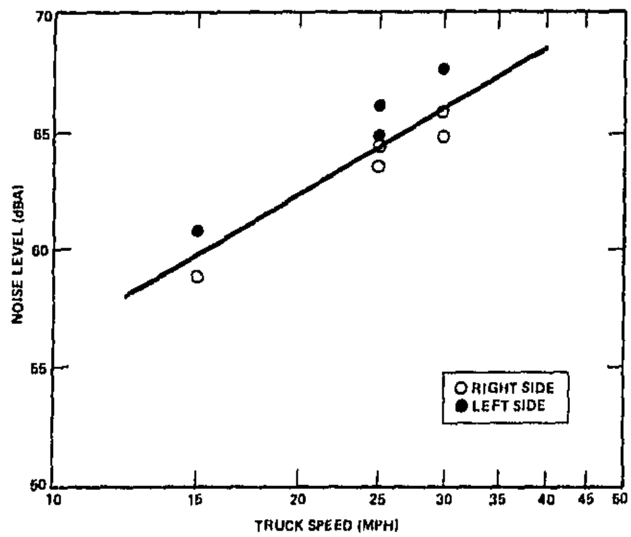

FIG. 6. VEHICLE COASTBY LEVELS.

logarithmic scale along with a least squares linear regression curve. The data illustrate that the contribution is approximately 62.5 dBA at the maximum speed of 20 mph reached during 40 CFR 205 tests.

Exhaust Noise

Two estimates were made of baseline exhaust noise levels. First, laboratory tests were conducted as described above for intake noise measurements. For exhaust noise tests, however, the microphone was located 50 ft from the exhaust stack. The peak level was 78 dBA, which occurred during a runup test. As indicated earlier, the results of this type of test correlate closely, but not exactly, with vehicle passby test levels.

A more precise estimate was made later by subtracting the intake (51.5-dBA), coastby (62.5-dBA), and engine/transmission (77.1-dBA) levels from the overall 81.7-dBA level. The resulting 79.8-dBA value is probably more indicative of the actual baseline level than is the 78-dBA value estimated from laboratory measurements.

Engine and Transmission Noise

For this project, the engine and transmission are treated as a single source, around which an acoustical enclosure is to be built. One way to estimate the source level of the engine and transmission is to subtract logarithmically the levels of all of the other sources from the overall level of the baseline truck. This approach was used to diagnose the other trucks that were quieted as part of this program. In contrast to the Ford vehicle, however, the engine and transmission contribution for the Brigadier is lower than that of the other sources together. As we will show, the exhaust level alone is nearly 3 dBA higher than the engine and transmission level. Therefore, small inaccuracies in determining the exhaust levels would be magnified when the engine/transmission contribution is computed.

When we installed a new exhaust system, the exhaust noise level was reduced to 60 dBA and the overall vehicle level was lowered to 77.3 dBA, leaving the engine/transmission as the dominant source. Subtracting the 60-dBA exhaust level, 51.5-dBA intake level, and 62.5-dBA coastby level from the overall vehicle level resulted in an estimated engine/transmission level of 77.1 dBA.

2.3 Summary of Component Levels

Figure 7 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 exhaust, with the engine and transmission 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 60 dBA a reasonable goal for exhaust and intake systems. An additional exhaust noise reduction of nearly 20 dBA, though substantial, is believed feasible with a dual system incorporating off-the-shelf equipment. The initial intake noise level of 51.5 dBA requires no further treatment. Reducing coastby noise beyond the present 62.5-dBA level would have little effect on the total truck noise level associated with the low-speed test used in this program. Moreover, it would probably require tire development, which could be extensive and is beyond the scope of this effort.

With the exhaust noise level reduced to 60 dBA and the intake and other levels each maintained at their initial levels, the engine/transmission goal becomes 71.1 dBA. This goal represents a 6-dBA reduction, which we planned to achieve by a tunnel-like enclosure.

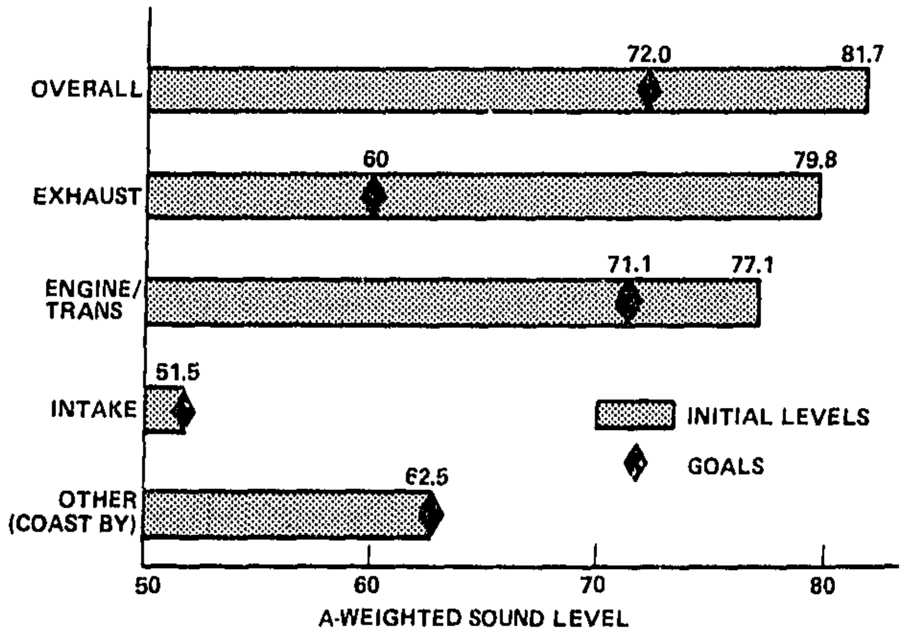

FIG. 7. OVERVIEW OF MAJOR NOISE SOURCE LEVELS AND GOALS.

3. NOISE CONTROL TREATMENTS

The principal noise control treatments installed by BBN were:

- Modifications to the exhaust system
- Installation of an open-ended enclosure around the engine and transmission.

These treatments are described in Secs. 3.1 and 3.2.

3.1 Exhaust System

The dual exhaust system installed on the vehicle is shown in Fig. 8. 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 AEM00-1337). 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 GM exhaust stack mast and mast bracket to the left side of the vehicle to accommodate the dual system. In addition, installation of the Splitter Tee Can required that a number of air lines be relocated farther to the left in the back of the cab to provide sufficient clearance and prevent damage to the lines from the heat of the exhaust system. The relocated lines are shown in Fig. 9.

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*The mufflers used on the truck were the bright stainless steel versions of this model.

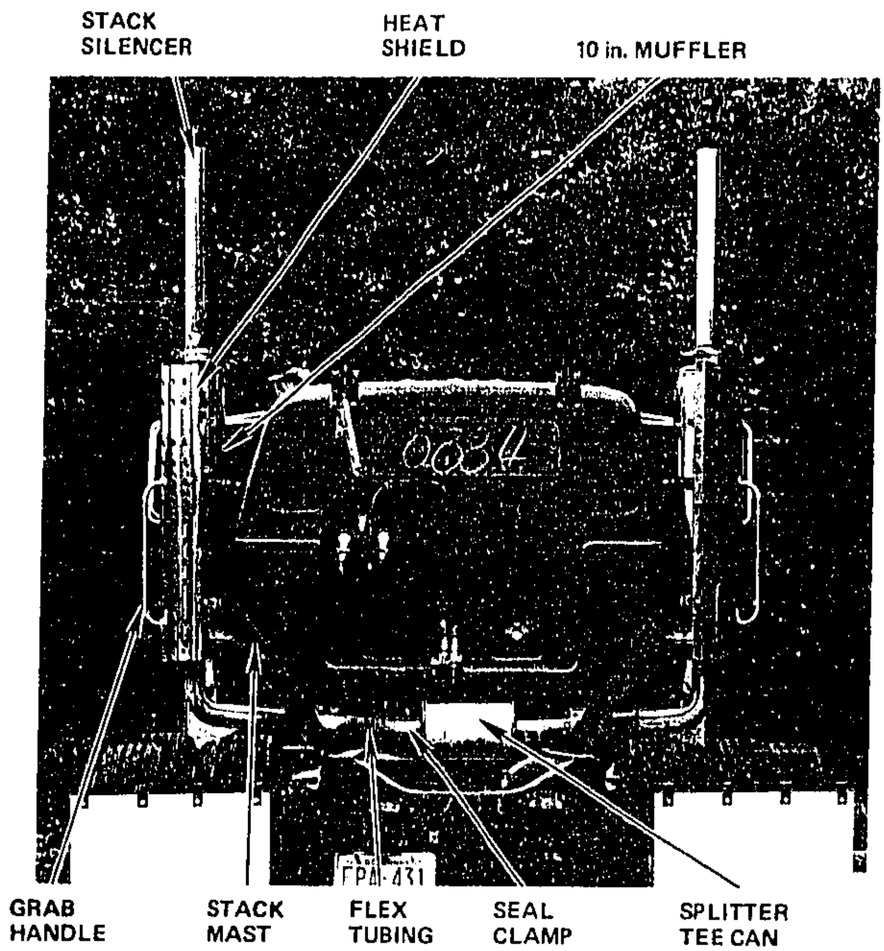

FIG. 8. DUAL EXHAUST SYSTEM.

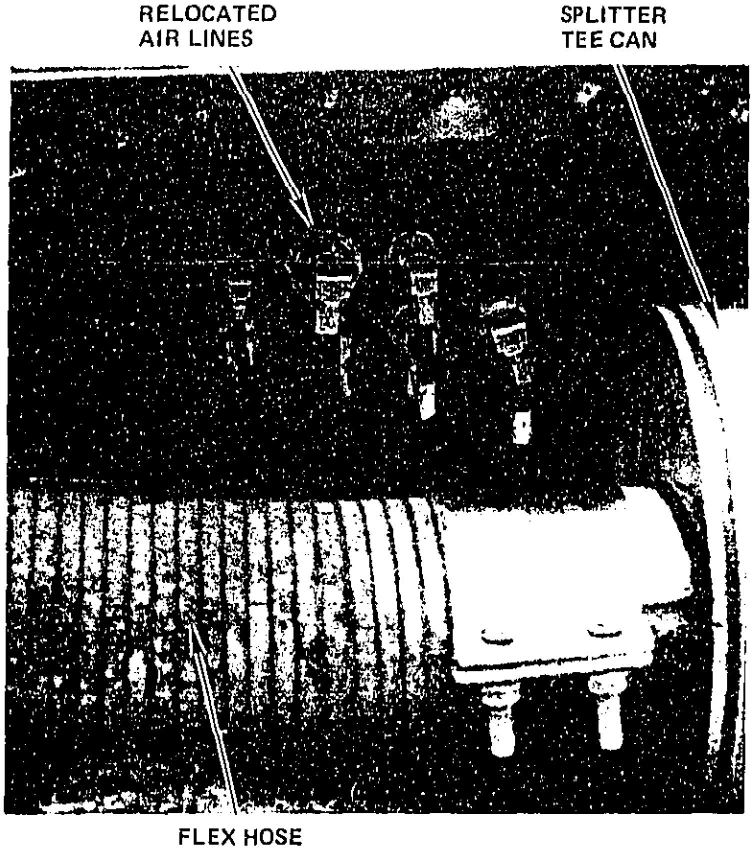

FIG. 9. RELOCATED AIR LINES.

Exhaust noise levels were measured for a single branch of the exhaust system, under laboratory conditions, as discussed in Sec. 2 for intake noise measurements. For these tests, a Detroit Diesel Allison 6V92TT engine rated at 272 hp at 1950 rpm was used, and A-weighted octave band sound levels were measured. Adding 2 dBA to the measured data to account for the presence of two exhaust lines on the truck gives the spectrum shown in Fig. 10. (A 2-dBA correction, rather than the 3 dBA that one might expect from elementary theoretical considerations, has been determined empirically to account well for the dual system.) Also shown in this figure are the A-weighted octave band spectra

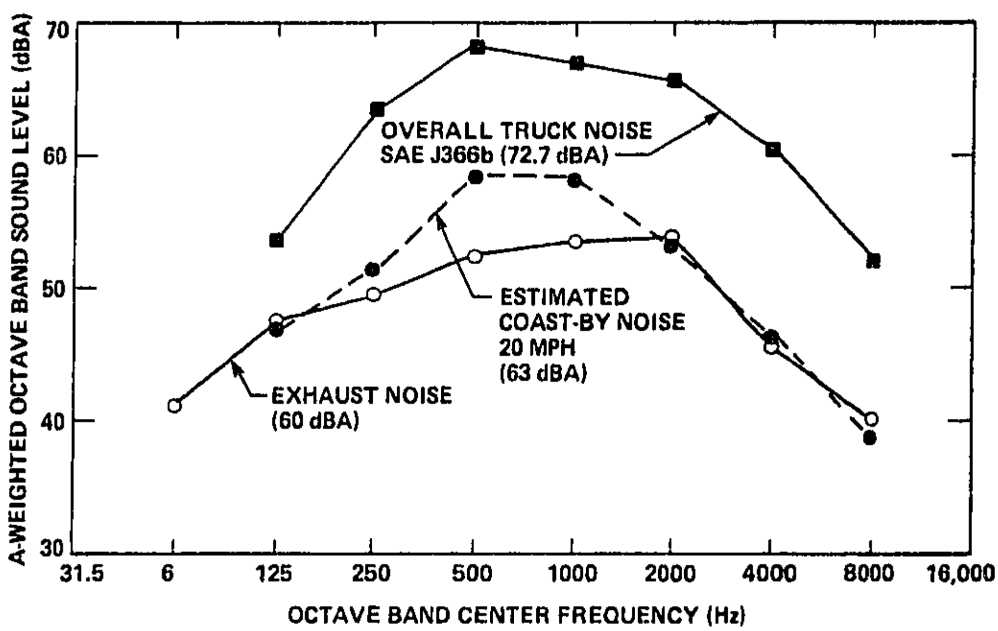

FIG. 10. ESTIMATED A-WEIGHTED OCTAVE BAND SPECTRUM OF EXHAUST NOISE: COMPARISON WITH OVERALL VEHICLE AND COASTBY SPECTRA.

of the final truck configuration* and the noise floor established by coastby tests. During testing according to the SAE J366b test procedure, the truck passes the microphone at about 20 mph. Coastby data were taken at 15 and 25 mph, and these spectra were interpolated within each band to obtain the estimated coastby spectrum in Fig. 10. The estimated exhaust noise level is about 10 to 15 dB below the overall vehicle level in all frequency bands except the 125-Hz band.

3.2 Engine/Transmission Treatment

The baseline contribution of the engine and transmission to the overall noise level was estimated to be 77.1 dBA. This source was treated with an acoustic enclosure built around the engine/transmission. The enclosure components are illustrated in Fig. 11 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.

*The spectrum shown is the average of two measurements made by BBN on the right-hand side of the truck. The overall noise level data for those two runs are given in Table 4 of Sec. 4.

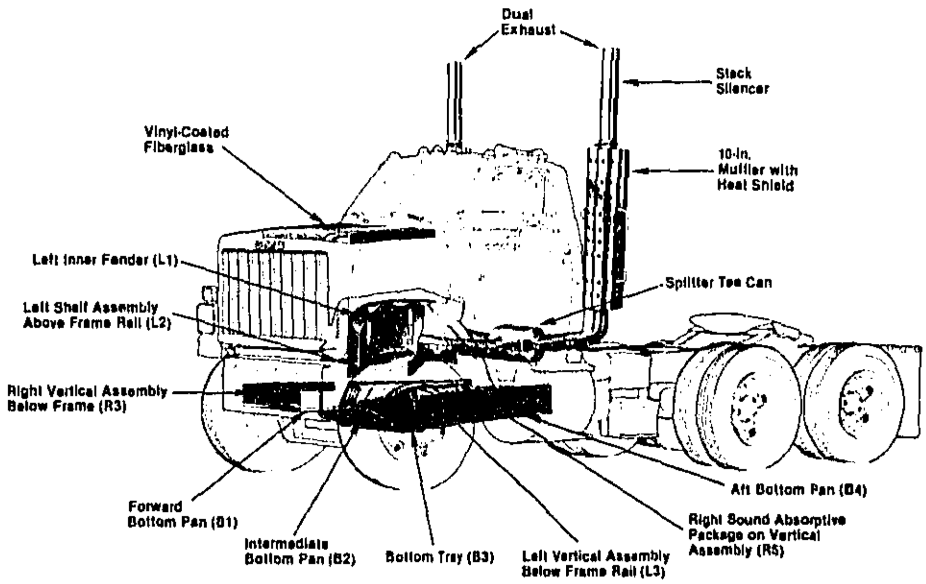

FIG. 11. NOISE CONTROL TREATMENTS INSTALLED ON GMC BRIGADIER.

TABLE 2. DESCRIPTION OF ENCLOSURE NOISE TREATMENTS.

Identifier	Description
L1 and R1	Left and right PVC inserts in innner fender.
L2 and R2	Left and right side shelves between inner fender and frame rail.
L3 and R3	Left and right side panels of the bellypan.
L4 and R4	Left and right gap shields between the cab floor and the frame rails.
L5 and R5	Left and right absorptive panels in rear of enclosure on each side of the transmission.
B1, B2, B3, and B4	Panels forming the bottom of the bellypan.

Enclosure Design Concept

A tunnel type of 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. 11 and described in Table 2, the hood and the bottom of the cab form the top of the enclosure. The remaining major areas requiring treatment to complete the enclosure are:

- The area between the inner fenders and the frame rails
- The area between each frame rail and the bottom of the cab
- The area beneath the engine and between the frame rails.

The Brigadier came equipped with removable inner fenders (1/4-in. EPDM*) and fender extensions (0.1-in. SMC†). These did not form a good seal against one another. Consequently, the fender extensions were removed and replaced with side shelves (panels L2 and R2) attached to the frame rails. In addition, inner fender inserts (L1 and R1) were added to the inner fenders to form a good seal against the shelves and thereby provide a barrier for engine noise escaping into the community from the wheel wells above the frame rails. The gap between the cab body and the frame rails was sealed with panels L4 and R4, and the bottom of the engine was enclosed in the bellypan formed from panels L3, R3, B1, B2, B3, and B4. These panels (with the exception of L4 and R4) are shown in Fig. 12.

The enclosure is fabricated primarily from sheet aluminum. While it is anticipated that a truck manufacturer would use an

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*Ethylene propylene dipolymer.

†Sheet molded compound.

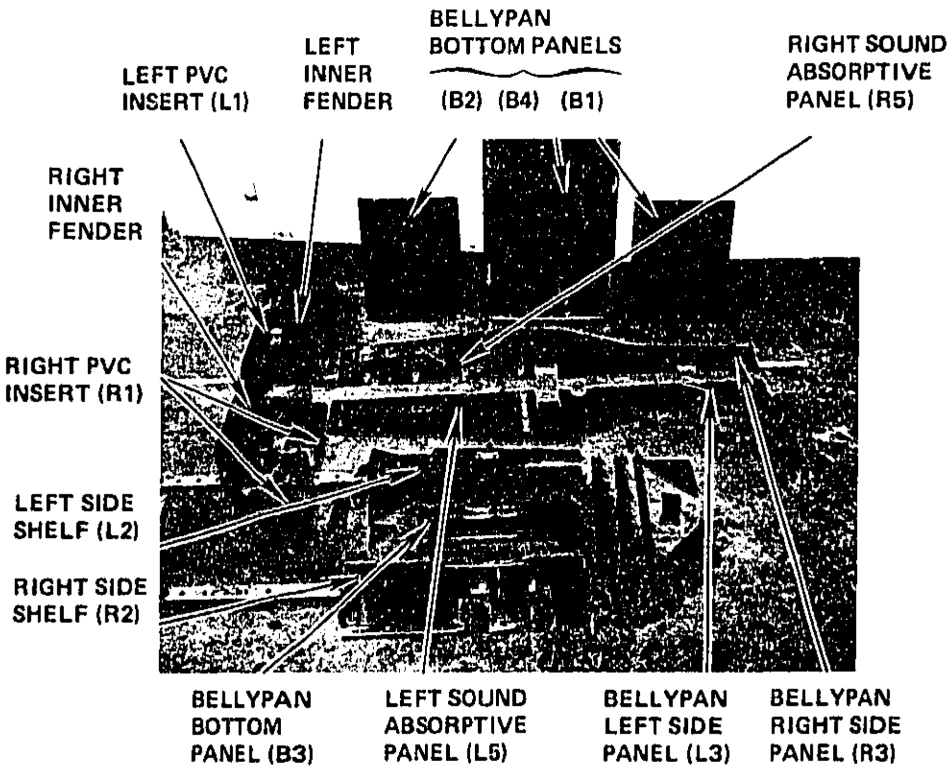

FIG. 12. ENGINE ENCLOSURE PANELS (Photo courtesy of GM).

alternate material (e.g., sheet steel), sheet aluminum is a light, rigid material well suited to prototype work. A minimum panel thickness of 1/8 in. was dictated by requirements for strength and durability rather than for noise reduction, and, as shown in Ref. 3, the 1/8-in. aluminum panel thickness is more than adequate to provide the required noise reduction.

Sound-Absorptive Material

Three types of absorptive treatments were used in the enclosure:

- GM baseline 1-in. fiberglass (2 lb/ft^3) with a sprayed-on vinyl coating
- BBN-installed 1.5-in. Mylar-wrapped fiberglass
- BBN-installed 2-in. aluminized polyester-covered foam.

The GM-installed absorptive treatment is found on the inner surface of the hood and on portions of the firewall, as described in Sec. 2. This material was left undisturbed.

The 1.5-in. Mylar-wrapped fiberglass was attached to panels L5 and R5. A cross-sectional view of the Mylar-wrapped fiberglass construction, used for additional treatment, is shown in Fig. 13. The basic absorptive material is 1.5-in. Owens-Corning 704 Fiberglas board. A similarly shaped piece of nylon

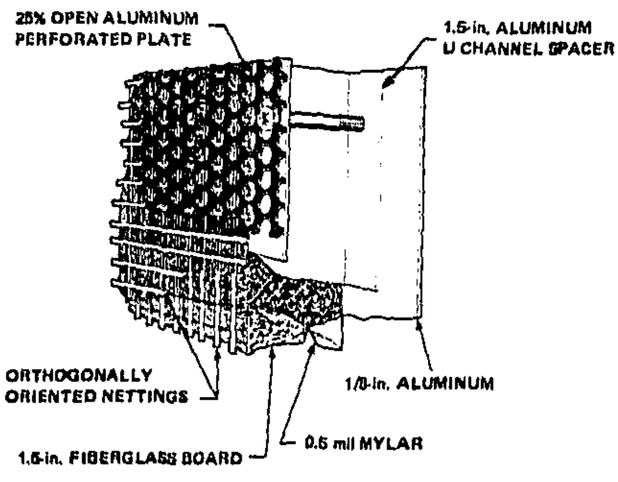

FIG. 13. DRAWING OF MYLAR-WRAPPED SOUND ABSORPTIVE TREATMENT.

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. These panels were installed in the rear of the enclosure on each side of the transmission, as shown in Fig. 11. This type of absorptive treatment and its acoustic performance have been described in Ref. 3.

The 2-in.-thick foam was installed in the top of the enclosure beneath the floor of the cab. The material is Tufcoat Acoustic Foam (TAF*), a continuously cast urethane foam with an aluminized polyester film on the exposed surface. The foam plus panels L5 and R5 form a partially lined duct to the rear of the enclosure.

Inner Fenders and Side-Shelves (R1, L1, and R2, L2)

Two side shelves, two inner fenders, and the hood form the enclosure forward of the firewall and above the frame rails. The right side shelf and inner fender are illustrated in Fig. 14. The inner fenders were part of the original equipment of the Brigadier, but they had to be modified so that they would meet the side shelf, leaving no large openings. The modification consisted of polyvinyl chloride (PVC) panels riveted to the inner fenders, as shown in Fig. 15. The right inner fender has two insert panels (R1), as shown in Figs. 12 and 15. The left inner fender has a single insert panel, as shown in Fig. 12.

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*Manufactured by Specialty Composites Corp., Newark, DE.

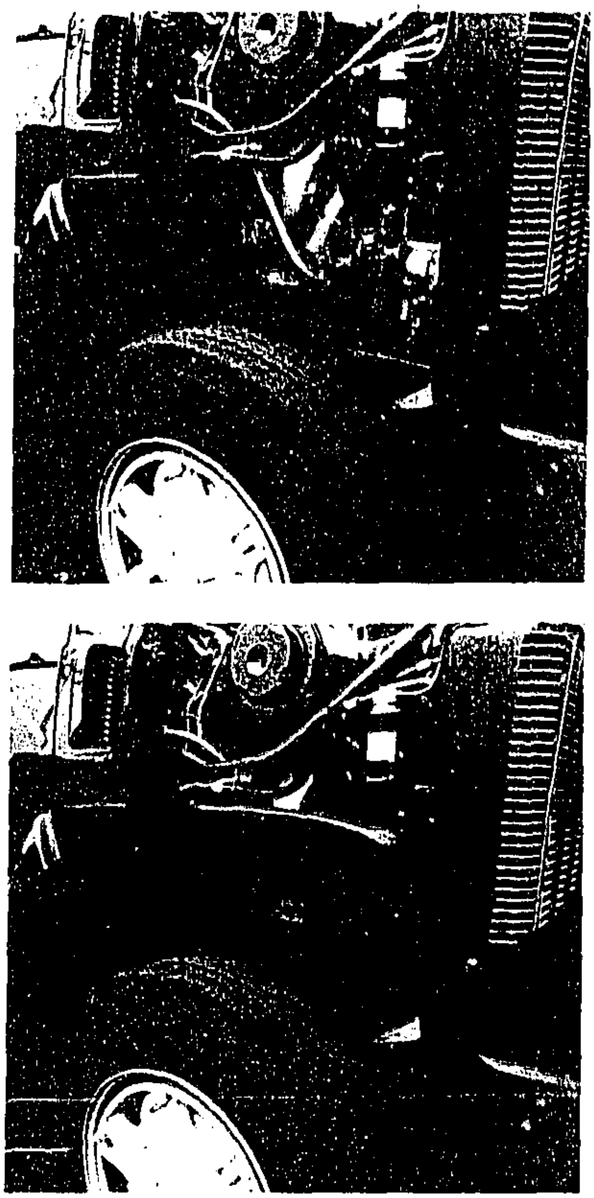


FIG. 14. RIGHT SIDE OF TRUCK SHOWING SIDE SHELF AND MODIFIED INNER FENDER.

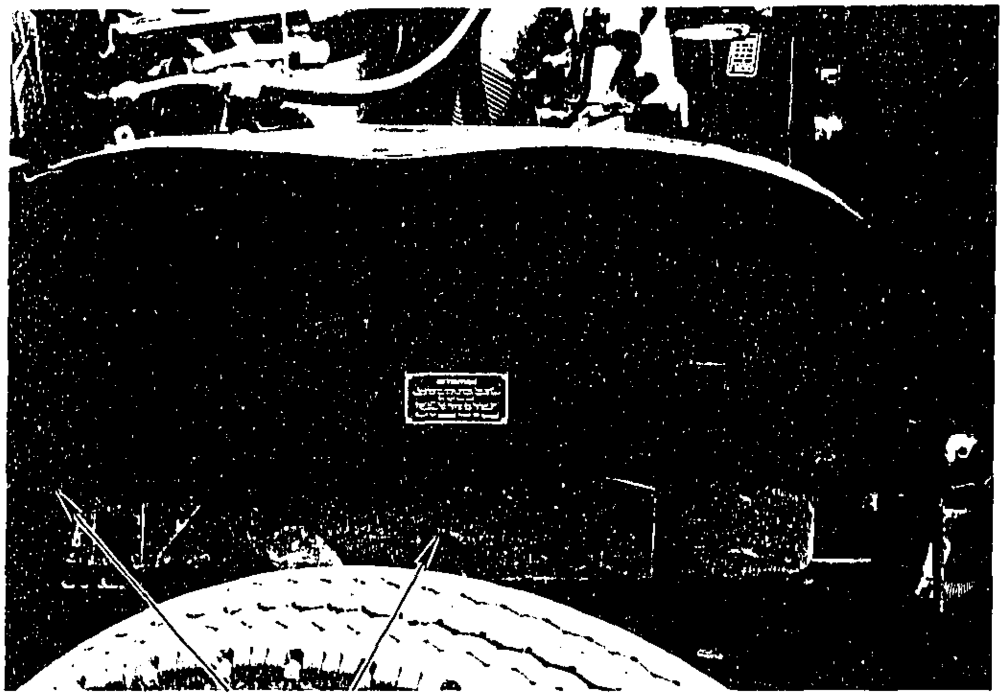


FIG. 15. PVC PANEL RIVETED TO INNER FENDER.

The side shelves, which were fabricated from 0.156-in. aluminum, attach to the frame rails and fill the space between the inner fenders and the frame rails. Figure 14 shows the side shelf on the right side of the truck. The shelves each rest on two brackets that are bolted to the frame. Figure 16 shows one of the brackets for the right side shelf, and also one of the air brake lines, which has been shielded with a steel spiral wrap. The purpose of the wrap is to prevent the mechanical damage to the brake line that might occur if the line contacts the overturned

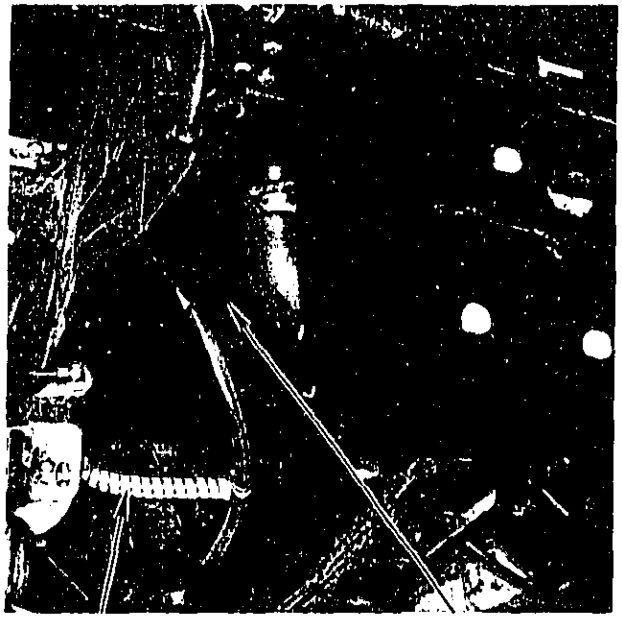


FIG. 16. SIDE SHELF ON RIGHT SIDE OF TRUCK AS SEEN FROM UNDERNEATH, LOOKING AFT.

lip of the shelf. Such contact, though unlikely, might occur if the wheel encountered a severe bump in the road. GM has pointed out that the possibility of contact between brake line and shelf would not be permissible in a production truck [7].

Gap Shields (L4, R4)

The gap shields fill the space between the cab floor and the frame rails. Figure 17 is an assembly drawing of the left gap shield. The three panels that form each shield are fabricated from 0.125-in. aluminum. The shields extend from the forward cab support bracket to the back of the cab.

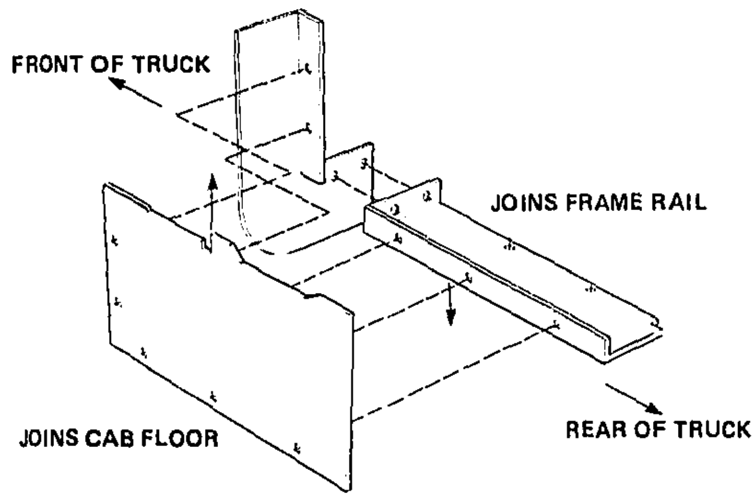


FIG. 17. ASSEMBLY DRAWING OF LEFT GAP SHIELD.

Bellypan (R3, L3, R4, L4, B1, B2, B3, B4)

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

- Maximum accessibility for maintenance purposes
- No reduction of ground clearance
- Quick 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 and one cross panel, B3, that is bolted to the side panels. The left side panel, L3, and the cross panel are shown in Fig. 18. These cross members and the cross panel maintain the

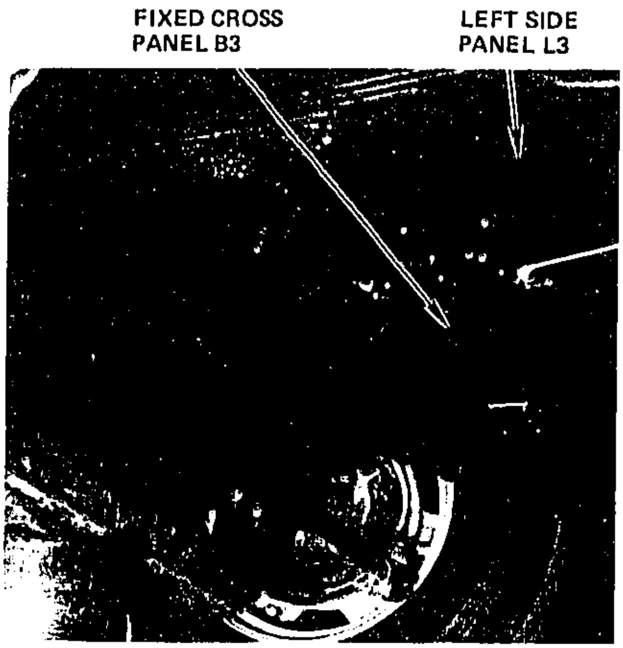


FIG. 18. BELLYPAN AS SEEN FROM UNDERNEATH TRUCK, LOOKING FORWARD TO THE RIGHT.

spacing between two side panels when the quick-release bottom panels are removed, yet they cause minimal access restriction. Three removable bottom panels (B1, B2, and B4) enclose the bottom area between the side panels. These three panels are shown in Figs. 19 and 20. The rear panel (B4) and one forward panel (B2) are attached with latches (DZUS Model TL 802). Figure 21 shows one of these fasteners on the rear bottom panel. The front panel (B1) is attached with quarter-turn fasteners, also shown in

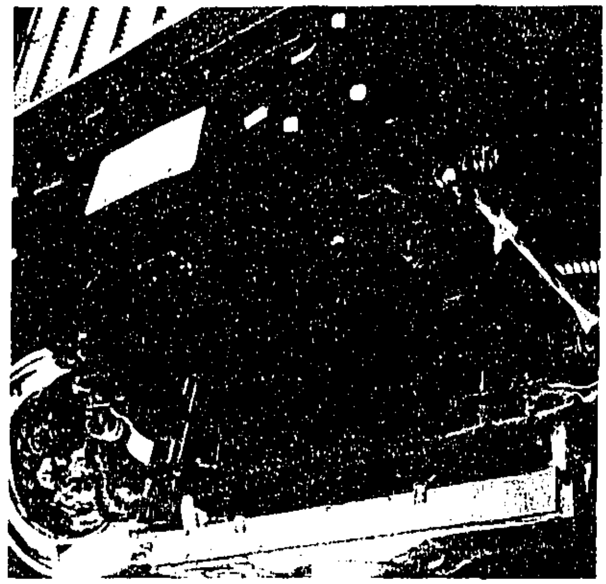


FIG. 19. BELLYPAN AS SEEN FROM UNDERNEATH TRUCK AT THE FRONT, LOOKING AFT.

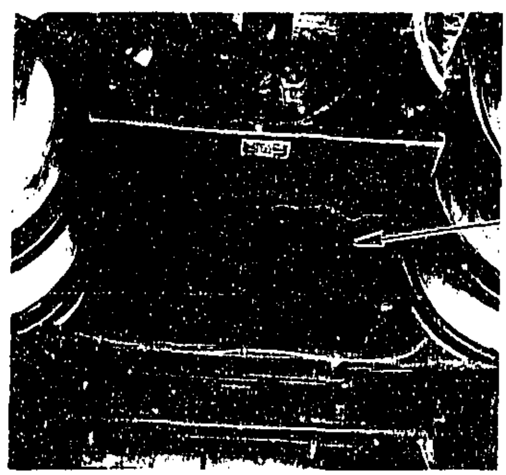
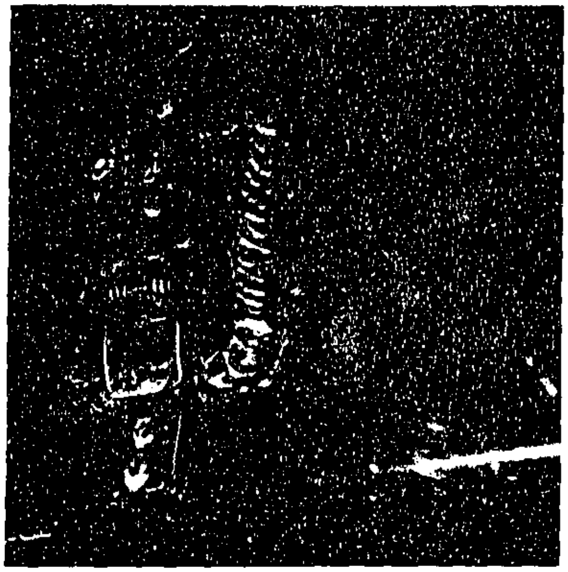


FIG. 20. BELLYPAN AS SEEN FROM UNDERNEATH TRUCK AT THE REAR, LOOKING FORWARD.

Side Latch



Quarter-turn
Fastener

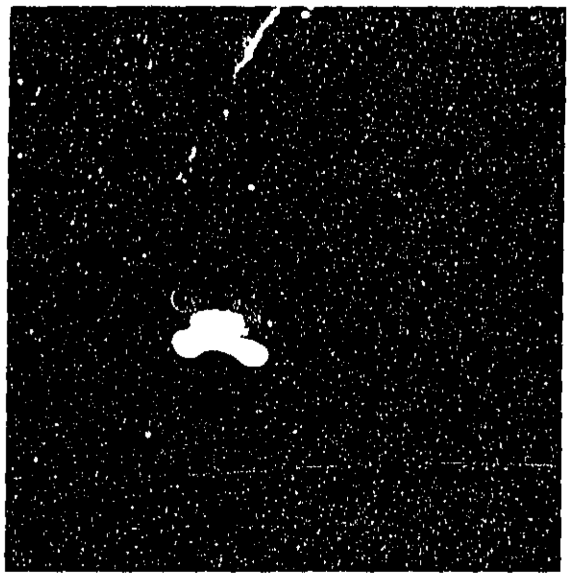
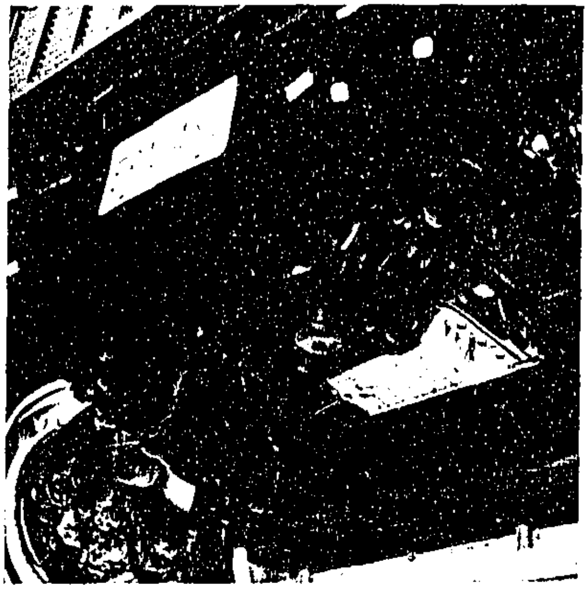


FIG. 21. QUICK RELEASE FASTENERS HOLDING BOTTOM PANELS OF BELLYPAN.

Fig. 21. Figure 22 shows the easy removal of that panel. All bottom panels are made from 0.125-in. aluminum. 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. 23, provide absorption at the acoustically important rear end of the enclosure.

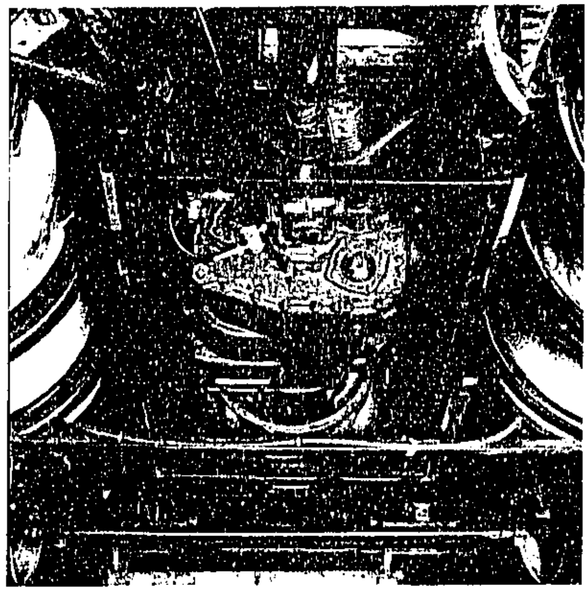
View With
Panel Removed



Panel Removal
Procedure

FIG. 22. REMOVAL OF BOTTOM PANEL AS SEEN FROM UNDERNEATH TRUCK AT THE FRONT, LOOKING AFT.

View From Underneath Looking Forward



View From Underneath Looking to the Left

FIG. 23. SOUND-ABSORPTIVE PANELS ON EACH SIDE OF THE TRANSMISSION.

4. FINAL NOISE LEVELS

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

4.1 Exterior Noise Levels

Table 3 summarizes the noise source contributions for the initial and final vehicle configurations. The 10.1 dBA reduction in overall vehicle noise was achieved through a 6.0 dBA reduction in engine/transmission noise and a 19.8 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	77.1	71.1	6.0
Exhaust	79.8	60.0	19.8
Intake	51.5	51.5	0
Other	62.5	62.5	0
Total	81.7	71.6	10.1

The tunnel enclosure produced a 6.0 dBA reduction, resulting in a final contribution of 71.1 dBA from the treated engine/transmission to the overall level.

Exterior noise levels were measured by BBN in Cambridge, Massachusetts, on July 3, 1980, and by EPA in Sandusky, Ohio, on July 29, 1980. The results, shown in Table 4, are in reasonable 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	72.4	71.9	72.7	71.5	71.6	71.6
Right Side	72.6	72.8		71.0	71.0	

4.2 Interior Noise Levels

Figure 24 shows the SAE J336a [8] criteria and the octave-band interior noise levels measured after the application of noise treatment. The criteria band levels shown in Fig. 24 are those that 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, are not to be exceeded if the vehicle is to meet the design criteria.

The truck meets the design criteria in that the sum of the measured band levels - 99.4 dB (86.5 dBA) - is less than the sum of the criteria band levels - 102.9 dB (87.6 dBA). The truck exceeds the criteria level by more than 3 dB, i.e., exceeds the maximum allowable band levels in the 1000-Hz and 4000-Hz bands. However, the levels in the 4000- and 8000-Hz bands are controlled by the rattling of the gear shift lever. If the shift lever is held by the driver during the test, the levels drop to 70 dB and 65.7 dB in the 4000-Hz and 8000-Hz bands, respectively.

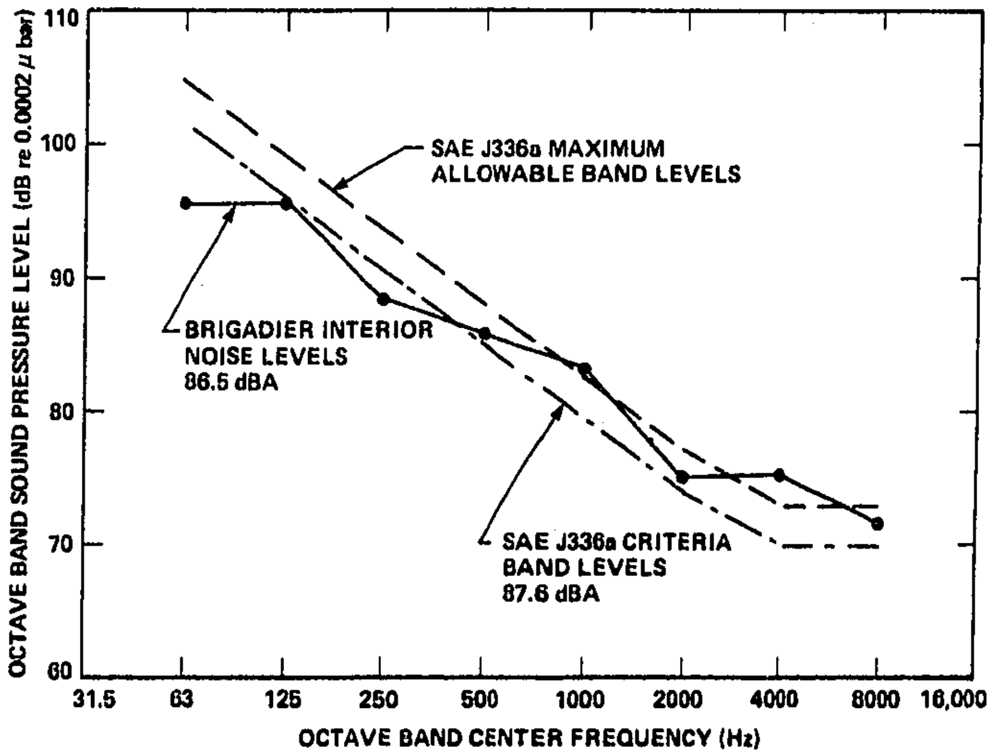


FIG. 24. TRUCK INTERIOR NOISE LEVELS MEASURED ACCORDING TO THE SAE J336a TEST PROCEDURE.

GM Tests

While the truck was at its facility for cooling tests, GM requested and received permission to conduct noise tests. The results for a variety of test conditions and vehicle configurations are shown in Table 5 [9]. The trailer used for tractor-trailer tests was equipped with rib type radial tires.

TABLE 5. MAXIMUM SOUND LEVELS OF GMC BRIGADIER (General Motors' test results).

Test Condition	Bamber Road Site Tractor Only No Load (dBA)	Military Straightaway Site Tractor-Trailer Except as Noted GVW 68520 Fan-On (dBA)	Military Straightaway Site Tractor-Trailer Except as Noted GVW 68520 Fan-Off (dBA)
J366b	71.6	75.2	70.6 (Tractor Only) 73.3 73.9
IMI	69.8		69.8
Idle			Approx. 55 (Level Near Ambient)
20 mph Cruise	71.2	74.6	71.2 (1950 rpm) 70.0 (1750 rpm)
20 mph Coast			63.2
35 mph Cruise		74.0 (1600 rpm)	71.9 (1600 rpm)
35 mph Coast			70.1
55 mph Cruise		78.0	77.7 (1750 rpm)
55 mph Coast			75.8

5. COOLING PERFORMANCE

Cooling tests were conducted in the GM facility illustrated in Figs. 25 and 26. Air introduced by a blower in front of the truck, as shown in Fig. 25, flows over the vehicle. The air is maintained at a constant speed and temperature during a test. Air speed is measured by a propeller-type anemometer located in front of the radiator, as shown in Fig. 26.

During the test, the truck runs on a chassis dynamometer. Heavy chains position the front set of the tandem rear wheels on a roller. The rear set of wheels is removed, allowing all of the truck output power to be transmitted through the roller and into the attached dynamometer. Exhaust gases from both stacks are piped outside of the facility.

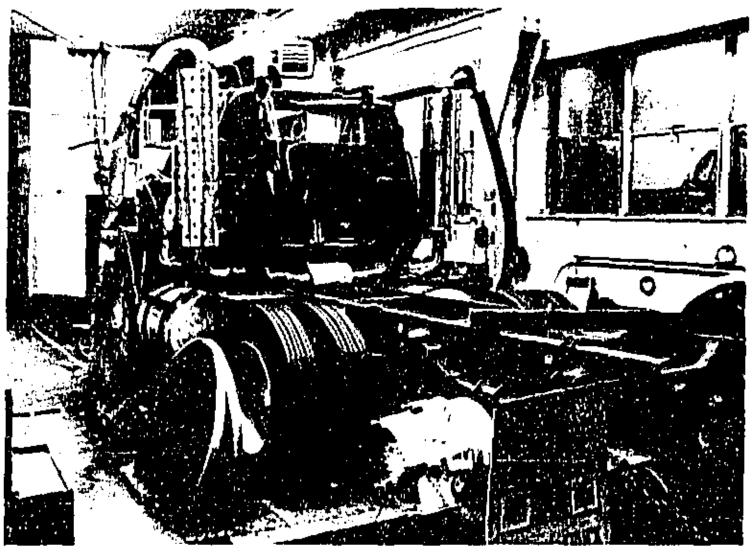


FIG. 25. REAR VIEW OF BRIGADIER IN GM COOLING TEST FACILITY (Photo courtesy of GM).

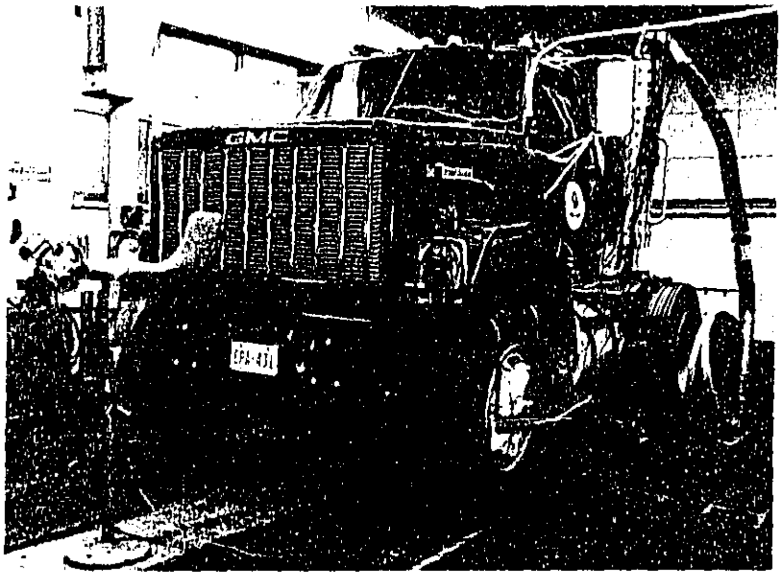


FIG. 26. FRONT VIEW OF BRIGADIER IN GM COOLING TEST FACILITY
(Photo courtesy OF GM).

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°F. That is,

$$ATB = 212 - T_i + T_a \quad , \tag{1}$$

where T_i is the coolant temperature measured at the radiator inlet and T_a is the 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.

An ATB test is conducted by operating the vehicle in an ambient wind flowing at a nominal 15 mph and 100°F. A valve in the thermostatically controlled fan is blocked open to ensure that the fan will be operative. The cab air conditioner is turned on to produce the heat that would normally be rejected by the condenser in front of the radiator. The engine is run at governed speed (1950 rpm) and at peak torque (corresponding to 1500 rpm) conditions.

All cooling performance tests were conducted during the same week with the truck in its final and (nearly) baseline configuration. To replicate the baseline configuration, insofar as practicable, we removed the complete bellypan and side shelves. The original fender extensions were not replaced but the inner fenders were left in place. These fenders are the same as the original inner fenders, except for the addition of a PVC insert as described in Sec. 4. The gap shields between the cab and frame rails were left in place because they would have been very difficult to remove and were judged to have little effect on cooling air flow.

The results of this test are shown in Table 6. It is apparent that the ambient and the operating conditions for the baseline and final configurations are very nearly identical for tests conducted at rated engine speed and at peak engine torque. The ATB drops by 4°F at rated engine speed and by 5°F at peak torque. The ATB is substantially above the value of 112°F specified by GM. For rated engine speed conditions, GM does not specify an ATB temperature at peak torque but requires the temperature of the coolant as it leaves the engine to be below 210°F [10]. Clearly, this condition is met.

The engine oil temperature rise associated with installation of the noise treatment is 5°F for rated speed and peak torque conditions. GM does not have an oil temperature specification for this test. However, GM does require oil temperature to be maintained in the 200-250°F range during vehicle operation. The engine oil temperatures lie within this range for all of the test conditions shown in Table 6.

TABLE 6. COMPARISON OF COOLING PERFORMANCE BEFORE AND AFTER TREATMENT AT RATED ENGINE SPEED AND PEAK TORQUE CONDITIONS.

	Rated Engine Speed		Peak Engine Torque	
	Baseline	Final	Baseline	Final
Air Speed (mph)	15.0	15.0	15.0	15.0
Air Temperature (°F)	100.0	99.0	100.0	100.0
Engine Speed (rpm)	1950.0	1950.0	1500.0	1500.0
Fan Speed (rpm)	1695.0	1702.0	1305.0	-
Vehicle Speed (mph)	58.2	58.3	44.7	44.7
Dynamometer Power (hp)	190.7	190.4	191.9	190.0
Engine Coolant Out (°F)				
Measured	186.0	189.0	194.0	199.0
Specified Maximum	-	-	210.0	210.0
Air to Boil @ 212°F (°F)				
Measured	126.0	122.0	118.0	113.0
Specified Minimum	112.0	112.0	-	-
Engine Oil (°F)				
Measured	229.0	233.0	234.0	239.0
Specified	*	*	*	*

*General Motors does not specify a value for this test but recommends the confinement of engine oil temperatures to the range between 200°F and 250°F during vehicle operation.

6. COST ESTIMATES

This section contains a discussion of 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. There is also the incremental cost of modification made to the cooling system to increase the cooling capacity and offset any temperature increases attributable to the engine/transmission enclosure. 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 is treated in the companion report covering the in-service test program.

Table 7 presents the distinctions between costs and price used in this report. The convention is that the seller sells at a price which is a cost to the buyer. A markup is applied in moving from one level of transaction to another. Hence, supplier's price x manufacturer's markup* = manufacturer's price, while manufacturer's price x dealer markup = dealer's price.

TABLE 7. 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

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*GM has pointed out that it does not include profit in its markup for changes mandated by the Federal government [7].

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 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 from Refs. 11 and 12.

6.1 Summary

Table 8 presents an overall summary of the treatment weights. Table 9 presents a summary of the estimated overall cost and price increase attributable to the noise control treatments installed on the Brigadier. The weight of the truck increased by 340 lb, approximately 2.4% of tractor tare weight, or 0.4% of the 80,000-lb maximum permissible gross combination weight. The estimated price increase of $1174 is a 2.8% increase over the $42,099 list price of the 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. Both cost and price estimates are expressed in 1979 dollars.*

The cost and price estimates presented here are BBN estimates for the add-on 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 tailor-made retrofit. More cost-effective

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

TABLE 8. SUMMARY OF TREATMENT WEIGHTS.

Treatment	Weight (lb)	Net Increase (lb)
Engine-Transmission Enclosure		157.6
• components added	165.1	
• components removed	<7.5>	
Exhaust System Modifications		166.5
• components added	262.1	
• components removed	<95.6>	
Cooling System Modifications		16.0
• 1400-sq-in. radiator installed	197.0	
• 1200-sq-in. radiator removed	<181.0>	
Total Weight	340.1	340.1

TABLE 9. SUMMARY OF COST AND PRICE INCREASES.

Treatment	Net Increase	
	Dealer Cost	Dealer Price
Engine-transmission enclosure	$435	$ 653
Exhaust system modifications	324	438
Cooling system modifications	55	83
Total	$814	$1174

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 Brigadier was to examine the relationship between the weight of materials and the cost of materials. This is a common technique used in industrial engineering. Obviously, 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 Brigadier, 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 made primarily 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. 27. A least-squares regression derived from the data is also shown as the dashed line on the figure. The estimated equation is:

$$Y = 61.3 + 1.92X \qquad R^2 = 0.99 \, , \tag{2}$$

where Y is manufacturer's price in 1979 dollars and X is enclosure weight in pounds.

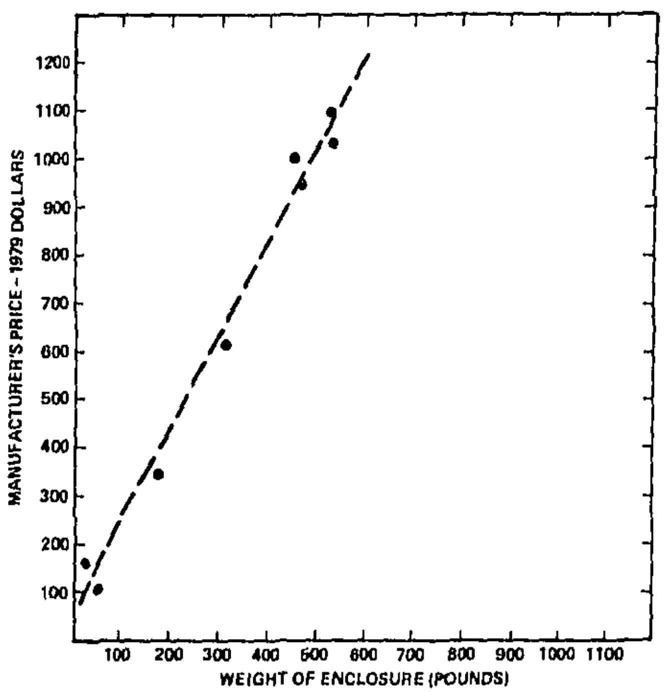

FIG. 27. RELATIONSHIP BETWEEN ENCLOSURE WEIGHT AND MANUFACTURER'S PRICE.

The coefficient of determination, designated R^2, 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 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, given an assumed dealer markup of 1.5).

This equation shows only the relationship between weight and manufacturer's price of a prototype enclosure. It does not include any costs for special tooling or research, development, and testing associated 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 components and weights for each assembly of the enclosure is presented in Table 10. The information presented in the table is based on physical measurements by BBN of the materials used in the construction of the enclosure. The bulk of the weight increase is accounted for by fabricated aluminum components, which constitute the sides and bottom of the enclosure. The weight increase of 165.1 lb is partially offset by the removal of two ethylene propylene dipolymer fender extensions (GMC Part Nos. 19020AA0 and 18020AAT), which together weighed 7.5 lb. Thus the net weight of the enclosure is 157.6 lb. In developing the cost estimates for the BBN enclosure, we

*These costs are estimated separately in the following section and added to an estimate obtained from the equation.

TABLE 10. SUMMARY OF ENCLOSURE ASSEMBLY AND COMPONENT WEIGHTS (lb).

Treatment Code	Assembly	Components	Component Weight (lb)	Assembly Weight (lb)
L1	Wheel Well Enclosure (Left)	PCV Inserts – Inner Fender	0.5	0.5
R1	Wheel Well Enclosure (Right)	PCV Inserts – Inner Fender	2.0	2.0
L2	Wheel Well Enclosure (Left) (Unmatched Pairs)	Shelf Panel	6.0	7.3
		Support Brackets (2)	1.1	
		Gaskets	0.2	
R2	Wheel Well Enclosure (Right) (Unmatched Pairs)	Shelf Panel	8.5	11.0
		Support Brackets (2 @ 1.0)	2.0	
		Gaskets	0.5	
L3 & R3	Bellypan Side (Matched Pair)	Side Panels – Right & Left (2 @ 19)	38.0	38.0
L4 & R4	Side Enclosure (Matched Pair)	End Caps (2 @ 0.8)	1.6	11.4
		Plates (2 @ 2.25)	4.5	
		Base (2 @ 2.4)	4.8	
		Gaskets	0.5	
L5	Absorptive Panel (Left)		9.0	9.0
R5	Absorptive Panel (Right)		10.0	10.0
B1	Forward Pan		12.0	12.0
B2	Intermediate Pan		10.0	10.0
B3	Bottom Tray		4.3	4.3
B4	Aft Pan		23.5	23.5
-	Lower Bellypan Mountings	Cross Supports	9.2	20.6
		Brackets	9.6	
		Misc. Fittings & Parts	1.8	
-	Under Cab Absorption	1600 sq in. of 2-in. Mylar-covered foam	5.5	5.5
	Total Weight		165.1	165.1

have considered the gross weight of the enclosure, 165 lb. The manufacturer and dealer prices of the fender extensions, which were removed, are estimated separately and then deducted from the gross weight and cost estimates.

Given the enclosure weight of 165 lb, and the weight-cost relationship expressed in Eq. 2, the estimated manufacturer's price of the enclosure is $378. Following the markup practice reported by Fax and Kay [11], we assume a markup of 1.5 is applied to manufacturer's price to obtain an estimated dealer price of $567. To put this estimate in perspective, we compared it to the overall weight and price of the Brigadier. The list base price of the 13,940-lb vehicle when it was acquired in late 1979 was $42,099, or $3.02 per pound. The estimated price of the enclosure, $567, yields a per-pound price for the enclosure of $3.44.

The estimated price estimates presented above exclude tooling and RD&T costs. These costs are influenced by a variety of factors, such as the complexity of the enclosure design, the materials used, and the production volume over which these costs can be allocated. To account for tooling and RD&T costs, BBN has taken the same percentage increase reported in Bender, Ernest, and Kane [3], 19%, and applied that as a markup.* This results in an estimated manufacturer's price increase of $450 and an estimated dealer price increase of $675. The estimate of $450 is obtained by multiplying the estimate of $378 obtained from Eq. 2 by 1.19. The product of that multiplication, $450, is then factored by the assumed 1.5 dealer markup to obtain the estimated price increase of $675.

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*BBN allowed $150 for tooling and RD&T costs of an estimated enclosure cost of $790, an allowance of 19%.

The final adjustment to these estimates is to credit the deletion of the inner fenders. These inner fenders weighed 7.5 lb. BBN assumes a manufacturer's price of $2 per pound for these components, which results in a $15 credit to manufacturer's price and a $22.50 credit to dealer price.

The estimated net manufacturer's price of the enclosure is therefore $435, while the estimated net dealer price is $653. The latter represents a 1.55% increase in the price of the truck.

6.3 Exhaust System Costs

The components used in the final exhaust system and their respective weights are presented in Table 11. The net weight

TABLE 11. SUMMARY OF EXHAUST SYSTEM COMPONENTS AND WEIGHTS.

Component	Weight (lb)
Installed	
Exhaust Mast (1)	41.0
Mufflers (2)	122.5
Heat Shields and Brackets (2)	26.0
Tee Can (1)	19.0
Stack Silencers (2)	20.0
Grab Handles (2)	6.0
Piping (85 in.)	19.5
Seal Clamps (6)	5.8
Flat Clamps (2)	2.3
Removed	
Original Muffler (1)	<65.0>
Piping	<27.5>
Clamps	< 3.1>
Net Increase	166.5

increase is the actual weight of components installed by BBN less components removed from the vehicle's exhaust system. The truck was delivered to BBN with a single vertical muffler exhaust system. This is an optional system that carries a list price credit of $248. The standard exhaust system for the Brigadier is dual vertical mufflers, and this system is included in the base list price. However, the estimates presented in this section represent the modifications made by BBN to the truck as received by BBN and not to the standard dual muffler system.

The approach used to estimate the price of the BBN system was to examine the components in the GM dual muffler system for which the dealer price differential of $248 over the single muffler system was known. The supplier price of components was known to BBN or could be reasonably approximated. The manufacturer's price of the mast was estimated to be $82, or $2 per pound. Thus, given these prices, the $248 differential between the single and dual muffler systems, and the system components, one could estimate the markups applied to the component prices by the manufacturer. These markups were then applied to the components installed by BBN.

The BBN exhaust component treatments were manufactured by Donaldson. Donaldson's prices were supplied to BBN to be used only for "computational purposes" in order to derive supplier costs for a complete system, without revealing the costs of individual components. A markup is subsequently applied to supplier's components to obtain the manufacturer's price. BBN estimates that markup to be 1.4, on the basis of the procedure described above. Dealer's price is estimated to be a markup of 1.35 over the manufacturer's price.

Two basic changes to the GM dual muffler system were made that could affect the price. First, the "wye" pipe connection that 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. They are comparable to the mufflers that would be installed as part of the dual muffler system, except that they incorporate a more expensive bright stainless steel outer wrap, rather than the standard aluminum wrap.

The costs and price of alternative exhaust systems are summarized in Table 12. The BBN system installed on the

TABLE 12. SUMMARY OF INCREMENTAL COST AND PRICE INCREASES FOR EXHAUST SYSTEM OPTIONS.

Exhaust System	Increase Over Single	
	Dealer Cost	Dealer Price
Single Vertical Exhaust System	$ 0	$ 0
GM Dual Vertical Exhaust System*	184	248
BBN Dual Vertical Exhaust System*	324	438
BBN Dual Vertical Exhaust System With Aluminized Finish*	221	299

*Includes Dual Mounting Masts

Brigadier is estimated to carry a $438 differential over a single muffler system and a $190 differential over the GM dual muffler system. Much of the increase attributable to the BBN system reflects the bright finish of mufflers and stack silencers used on the Brigadier. There is a premium at the supplier price level for having this bright stainless steel finish rather than 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 have an incremental dealer cost of $221 and an incremental dealer price of $299.

6.4 Cooling System Modification

A standard 1235-sq-in. radiator is installed on Brigadiers equipped with the 6V92TT engine. In anticipation of potential cooling problems caused by the engine enclosure, this radiator was replaced with a larger 1405-sq-in. radiator. This replacement was made by GM, at BBN's request, before the vehicle arrived at BBN.

GM reports that this change would increase the dealer price of the vehicle by $83. We did not have access to radiator price data and could not make an independent check of the GM estimate. However, we do accept the GM estimate as reasonable. It implies a price per pound for the radiator of $5.19, i.e., $83/16 lb. One would expect a radiator to have a relatively high per-pound price, given the materials used in it and the complexity of its fabrication. Accordingly, we have attributed a price increase of $85 for the radiator change and assumed a 1.5 markup on the manufacturer's price of $55.

6.5 GM Estimate

At BBN's request, GM inspected the truck and estimated the cost to the consumer of the noise treatment. GM estimated that the BBN treatment would increase the 1981 model price for this truck by $1500. GM based its estimates on the less expensive aluminized exhaust system and did not provide any back up or breakdown of its figure. In addition, GM did not consider adapting the BBN design to production or to the cost of a production treatment [13].

It is necessary to express the BBN and GM estimated price increases on a common basis in order to compare them. The Producer Price Index for heavy trucks, Series 14110281, is used to convert GM's 1981 price increase of $1500 to 1979 dollars, in which BBN's estimate of $1174 is expressed. The heavy truck price index stood at 223.1 in 1979; by mid-1981 it had risen to 283.0.*

Table 13 presents a comparison of the BBN and GM estimates. The close agreement of the BBN and GM estimates in 1979 dollars is readily apparent.

TABLE 13. COMPARISON OF BBN AND GM ESTIMATED PRICE INCREASES.

Source	Year	Price Index	Estimated Increase
GM	1981	283.0	$1500
GM	1979	223.1	1183
BBN	1979	223.1	1174

*This is the value for June 1981; 1981 annual figures will not be available until early 1982.

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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 GM. These test procedures are described in considerable detail in documents which should be consulted by readers who wish to understand them fully (see Refs. 6 and 8 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 [6]. The general arrangement of the test site is illustrated in Fig. 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.

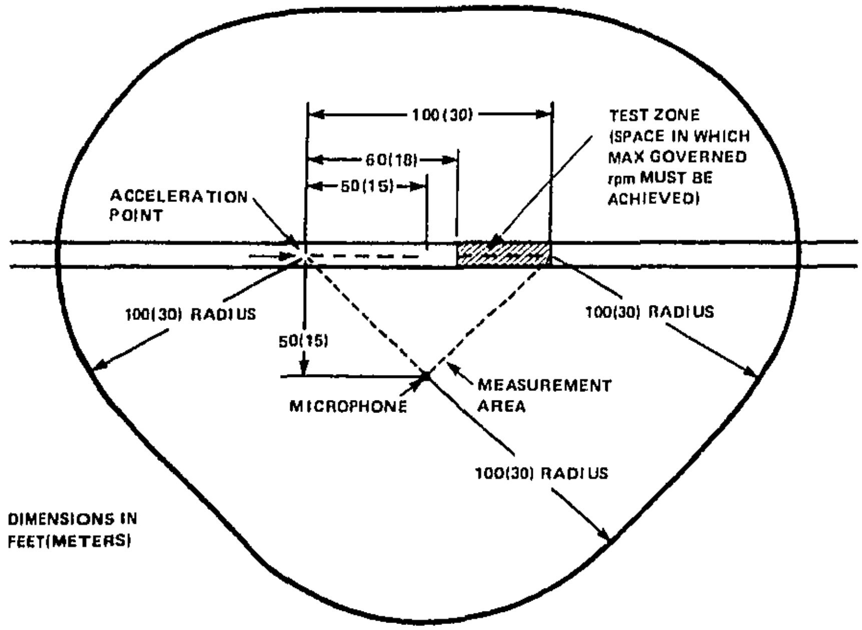

FIG. A.1. TEST SITE FOR EXTERIOR NOISE LEVEL MEASUREMENTS.

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

Engine Speed	- approach:	1200 rpm*
	- final:	2100 rpm
Vehicle Speed	- approach:	11 mph
	- final:	20 mph
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 that, starting at 1200 rpm, governed speed was reached within the test zone.

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. 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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