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EPA 550/9-82-331F

Field Test of a Quieted Ford CLT 9000 Heavy-Duty Diesel Truck

Environmental Protection Agency

October 1981

Demonstration Truck Program

6

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 describes the field test and operational performance evaluation of a quieted Ford CLT 9000 heavy-duty diesel truck. The noise of the truck had been reduced from 77.1 dBA to 72.3 dBA. The field test showed the noise control treatments to be effective and durable in over 100,000 miles of service. The treatments had no adverse impact on the vehicle's operation and appear to have had negligible effect on fuel consumption. Incremental maintenance time of 2.5 hours was attributable to the treatments' impact on normal annual vehicle maintenance.

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FIELD TEST OF A QUIETED FORD CLT 9000 HEAVY-DUTY DIESEL TRUCK

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PREFACE

This report deals with the field testing by Bolt Beranek and Newman Inc. (BBN) of a quieted Ford CLT 9000 heavy-duty diesel truck, one of the heavy-duty diesel trucks in the Environmental Protection Agency's Demonstration Truck Program. The objective of this program, begun in 1979, was to demonstrate noise reduction technology for heavy-duty diesel trucks. The program included four 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, preventing all four vehicles from completing a year of fleet service. The Ford CLT 9000 was one of two vehicles that completed an entire year of field testing.

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. Each report is intended to be internally complete; therefore some redundancy occurs between the technology and cost reports and the field test reports. For example, a reader who has read the technology and cost report for a particular truck will find that he can pass over Sec. 2 of the companion field test report for that vehicle.

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 on the 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 Laboratories and the Massachusetts Port Authority. The Tom Inman Trucking Company, Inc. operated the truck in its fleet and supplied much of the operational information provided in this report.

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1. INTRODUCTION

This report describes the field test and operational performance evaluation of a quieted Ford CLT 9000 heavy-duty diesel truck tractor. It is one of four vehicles in the Quiet Truck Demonstration program sponsored by the Environmental Protection Agency (EPA). The objectives of the Quiet Truck Demonstration program are to reduce the noise level of four heavy-duty diesel truck tractors to 72 dBA and to evaluate the technology, costs, and performance impacts of achieving this reduction.

The first phase of the program is the development of noise control treatments to reduce truck noise to the 72-dBA target level. A thorough discussion of the baseline noise sources, the noise control treatments, and the associated price increases for the vehicles in this program (a Ford CLT 9000, a GMC Brigadier, an International Harvester F-4370, and a Mack R686) is presented in separate reports [1-4]. The quieted vehicles enter fleet service during the second phase of the program. The objectives of the year-long field test are to determine the technical feasibility of the treatments and their impact on operating performance and cost.

The field test of the Ford CLT 9000 was conducted by the Tom Inman Trucking Co., Inc., of Tulsa, Oklahoma. The test was directed by Bolt Beranek and Newman Inc. (BBN), EPA's contractor for the demonstration program. The vehicle logged over 100,000 miles during the year-long field test, from February 1980 to January 1981.

The field test results are highlighted below and described in detail in the remainder of this report. The major findings are as follows:

- The treatments proved to be effective and durable. The noise level of the truck did not significantly increase over time, and, except for one specific component, the treatments show no significant deterioration.

- The treatments had no adverse impacts on the operation of the vehicle. Its use was significantly higher than comparison vehicles in the fleet, and there was no evidence of payload displacement.

- The weight of the treatments appears to have had negligible effect on fuel consumption. The quieted unit had fuel economy of 3.78 mpg in comparison to a fleet average of 3.83 mpg. This difference is not believed to be statistically significant.

- The treatments had a minimal impact on maintenance. Approximately 2 1/2 hours of incremental labor time was attributable to the removal or interference of treatments while maintenance tasks were performed over the one-year period.

Section 2 presents a summary description of the Ford CLT 9000 and its noise reduction treatments. Details on the administration of the field tests and actual operations are given in Sec. 3. Section 4 presents a technical evaluation of the noise control treatments installed on the truck. Fuel economy impacts are described in Sec. 5, and maintenance impacts are provided in Sec. 6. Section 7 presents the conclusions drawn for the field test.

2. DESCRIPTION OF THE QUIETED FORD CLT 9000

The Ford CLT 9000 had an original baseline noise level of 77.1 dBA. Its noise level was reduced to 72.3 dBA. This section describes the treatments employed to achieve this reduction. Readers who have already read the companion technology and cost report [1] may wish to skip this section, since it is a summary of information presented in that report.

2.1 Description of the Truck

The baseline configuration of the Ford CLT 9000 is shown in Fig. 1. The specifications of the vehicle are summarized in Table 1. The truck is equipped with a Caterpillar 3406 PCTA

FIG. 1. BASELINE CONFIGURATION OF THE FORD CLT 9000.

TABLE 1. SPECIFICATIONS SUMMARY OF THE FORD CLT 9000.

Component	Specification
Vehicle Identification Number	X98ZVDD0540
Wheelbase	152 in.
Bumper to back of cab	88 in.
Gross Vehicle Weight	44,860 lb.
Gross Combination Weight Rating	80,000 lb.
Engine	Caterpillar 3406 PCTA (340 hp @ 1,950 rpm)
Transmission	Fuller RTO 12513
Rear Axle	Eaton DS-380 (4.33 to 1)
Rear Suspension	Reyco 101-F
Fan Diameter	32 in.
Fan Clutch	Eaton 340

in-line six-cylinder engine rated at 340 hp at 1,950 rpm and a Fuller RTO 12513 transmission that has 13 forward speeds. Fully fueled and with a driver, the truck weighs 18,220 lb and has a gross combination weight rating (i.e., with loaded trailer) of 80,000 lb. The sleeper-type cab is suspended at each corner by a pneumatic spring for ride control.

The baseline configuration did include initial noise treatments. The truck was equipped with a single 5-in.-diameter exhaust line containing a 10-in.-diameter, 44 1/2-in.-long double-wrapped muffler. It had a 32-in.-diameter thermostatically controlled fan that was disengaged during noise tests, as prescribed by 40 CFR 205, [5] and was equipped with ribbed tires. Engine noise was partially absorbed by 1-in.-thick foam faced with an aluminized polyester mounted on the underside of the cab. Additional noise shielding on the baseline CLT 9000 included engine side shields, an oil pan cover, and transmission side and bottom shields.

Initial noise levels were measured by EPA at its Noise Enforcement Facility in Sandusky, Ohio, and by Bolt Beranek and Newman Inc. (BBN) at Hanscom Field in Bedford, Massachusetts. Both tests were performed in accordance with the 40 CFR 205 [5] test procedure, which is nearly identical to the SAE J366b Recommended Practice. The results, shown in Table 2, are fairly consistent between sites. Figure 2 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.

TABLE 2. INITIAL NOISE LEVEL MEASUREMENTS FOR THE FORD CLT 9000.

	Measured Level	
	EPA (dBA)	BBN (dBA)
Ford CLT 9000	76.4	77.1

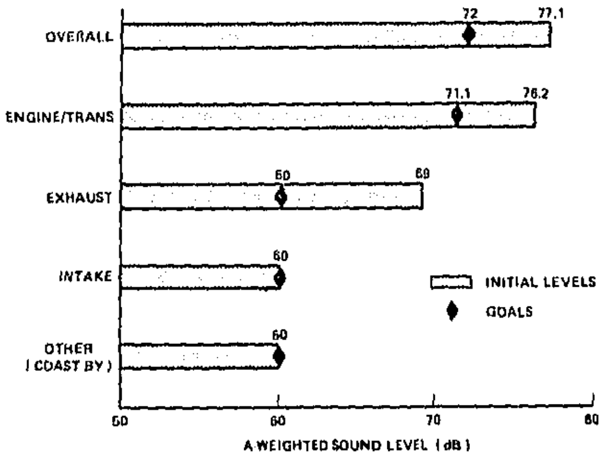

FIG. 2. OVERVIEW OF MAJOR NOISE SOURCE LEVELS AND GOALS.

2.2 Description of Noise Control Treatments

The principal control treatments installed by BBN were:

- modifications to the exhaust system
- an open-ended enclosure around the engine and transmission.

A minor modification to the rear spring bracket was also made. Figure 3 is a graphic representation of the BBN treatments.

Exhaust System Modification

A dual exhaust system was installed that had three major types of silencing components: a Splitter Tee Can, a 10-in.-diameter muffler, and a 4-in.-stack silencer. A 5-in.-diameter

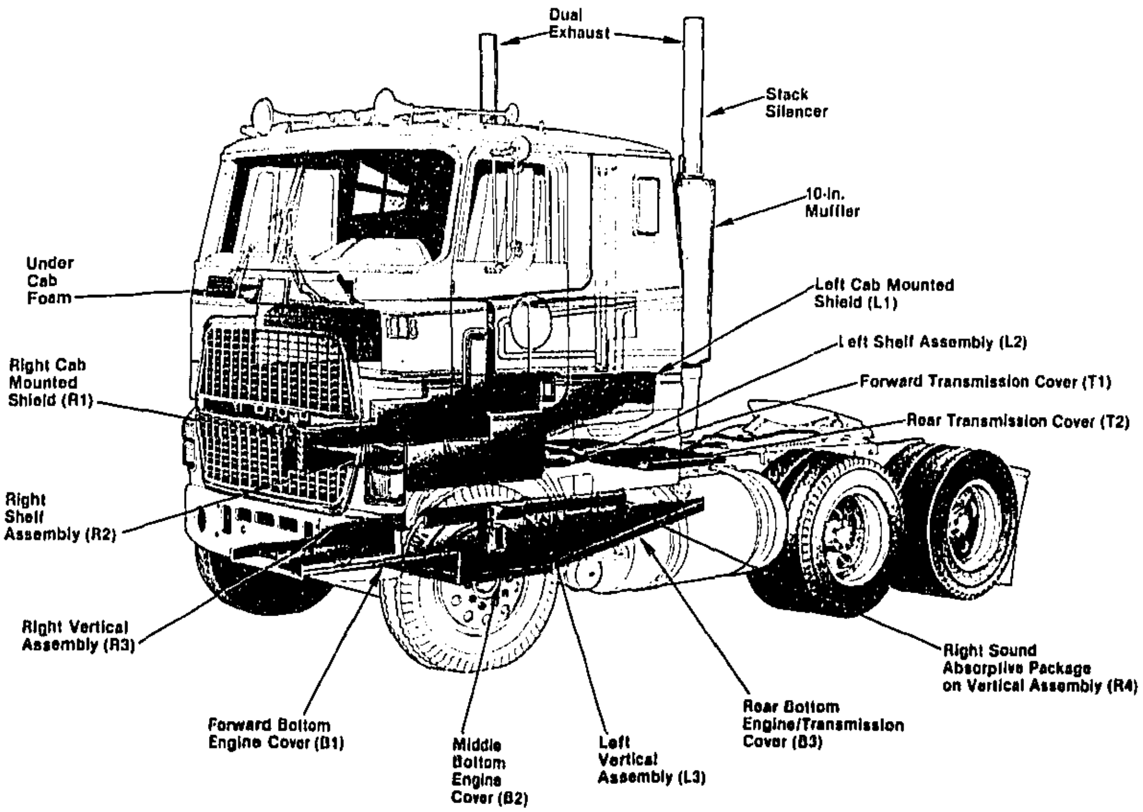

FIG. 3. NOISE CONTROL TREATMENTS INSTALLED ON FORD CLT 9000.

exhaust line, consisting of aluminized steel tubing and stainless steel flex hose, leads from the turbocharger to the Splitter Tee Can. 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 and a 4-in. stack silencer. The stack silencer 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 exhaust stack mast to accommodate the dual system.

Engine/Transmission Enclosure

As shown in Fig. 3, the enclosure is a tunnel-like structure leading from the radiator to the rear of the cab. As much of the existing cab and chassis structure as is practical is used to form this structure. Spaces between the cab and top of the frame rails are filled in with side shields and shelves, and a bellypan extends from one frame rail, under the engine and transmission, to the opposite frame rail.

A rear view of the CLT 9000 shows some of the major features of the noise treatment (see Fig. 4). The original deck plate over the rear of the transmission was left in place but lined with sound-absorptive material. A forward transmission cover (also lined with absorptive material) was added to enclose the transmission further. Both side shields are lined with sound-absorptive material and tip up with the cab to which they are fastened when the cab is tilted to service the vehicle.

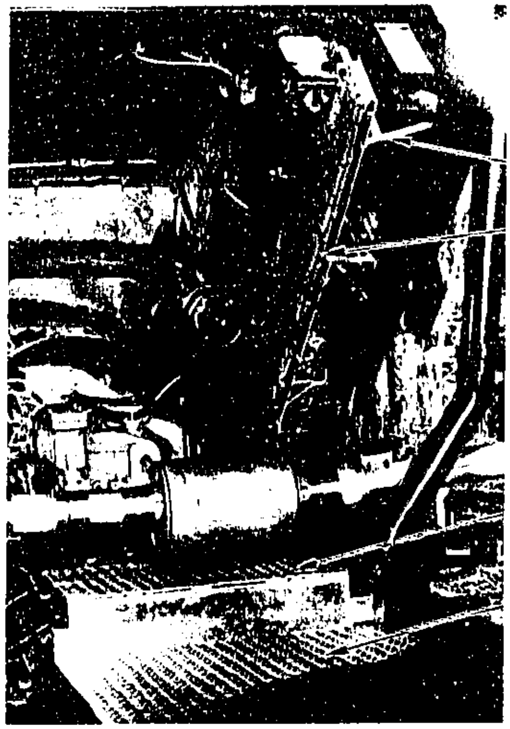

FIG. 4. REAR VIEW OF CLT 9000 WITH CAB IN PARTIALLY RAISED POSITION.

Figure 5 shows how the side shelf assembly connects the side shield with the frame rail. The assembly consists of a shelf, several support gussets, and a wiping neoprene seal. The shelf and gussets are fabricated from 0.160-in. aluminum and are sturdy enough to stand on. The neoprene seal is designed to accommodate the vertical motion of the side shield, which moves with the pneumatically suspended cab. The bellypan assembly consists of two side panels that extend downward from each frame rail and are connected by three bottom panels.

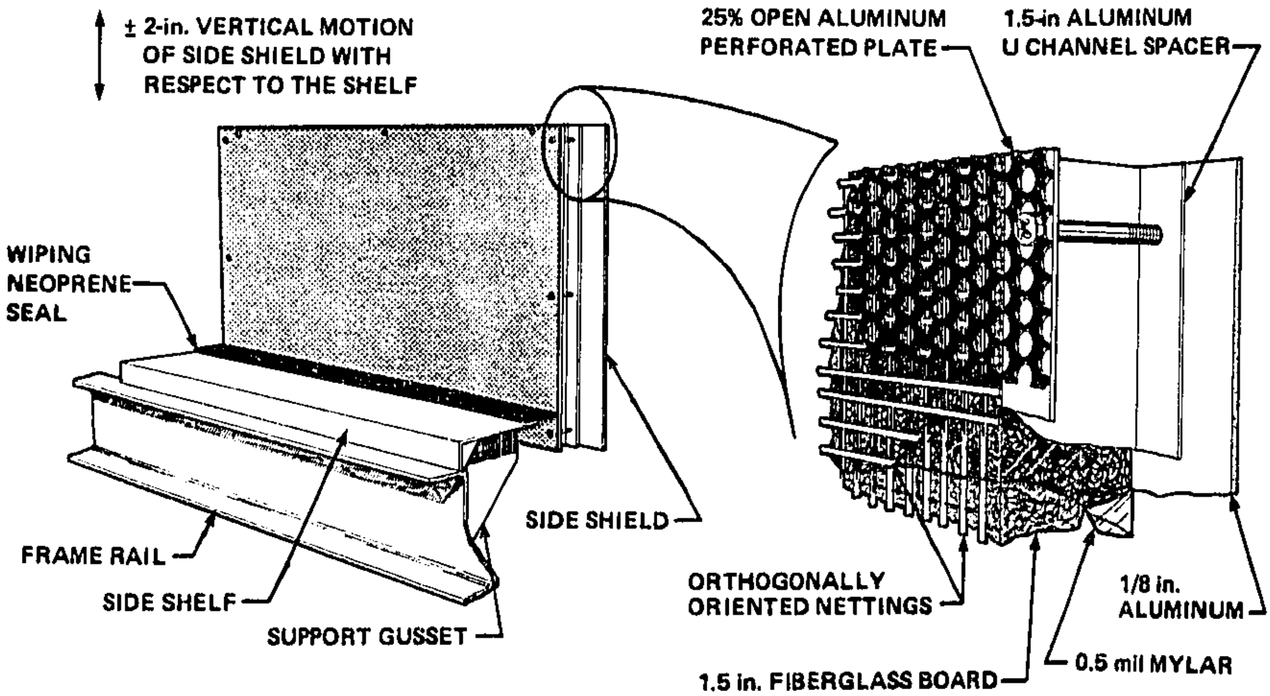

FIG. 5. ILLUSTRATION OF SIDE SHELF ASSEMBLY AND DETAILS OF CONSTRUCTION OF SOUND ABSORPTIVE MATERIAL.

Identifiers for each component of the engine/transmission enclosure are presented in Table 3.

TABLE 3. 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 assembly below frame rail
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

3. FIELD TEST OPERATIONS

The field test was conducted from February 1980 to January 1981 by Tom Inman Trucking Company, Inc. (Inman), of Tulsa, Oklahoma. This section presents a description of the field test itself and a discussion of the quieted truck's operating performance.

3.1 Administration of the Field Test

Selection of the operator of the quieted truck for the field test was based on several criteria. First, the operator had to have a fleet of comparable vehicles to provide a basis of comparison. Second, the operator had to have management information systems that would routinely provide data on the operations and maintenance of the truck. Third, the operator had to provide 100,000 miles of service for the test.

Inman was identified as an operator that met these criteria. Inman had a fleet of 38 Ford CLT 9000s with Caterpillar 3406 PCTA engines.* These would provide a basis of comparison. The company appeared to have a good reporting system and had recently moved into new headquarters with excellent maintenance facilities. Inman agreed to provide data on the truck's operation in exchange for having the use of the truck.

Inman is an irregular-route common carrier, with a fleet of 350 line haul tractors based in Tulsa. Trucks in the Inman fleet do not operate in regular service between Tulsa and other cities, but rather travel throughout the country dropping off and picking up loads along the way. The quieted Ford CLT 9000, Unit 455 in the Inman fleet, was to operate in this manner. A typical pattern for Unit 455 would be to start in Tulsa with a load that originated somewhere else and had been brought through Tulsa by a

*Units 417 to 454 in the Inman fleet.

truck returning to the Tulsa base. Unit 455 might deliver that load to Oregon and then pick up another load for delivery to Illinois. After delivery in Illinois, Unit 455 would pick up yet another load and deliver it to Tulsa or through the Tulsa terminal to a final destination. Thus, the truck had a different payload over each trip segment, and the operating conditions on each segment - e.g., terrain, temperature - varied dramatically.

Procedures were developed to monitor the vehicle's fuel, payload, and maintenance. These procedures are presented schematically in Fig. 6. Original source documents, freight bills, fuel records, etc., were collected by the data coordinator, who prepared an operations and maintenance information summary. This is shown in Fig. 7. An information summary was prepared for each trip and for maintenance to the vehicle at the end of the trip. The information summaries were sent to BBN monthly. Each summary and attached documents were reviewed by BBN and then loaded on BBN's RS/1 computer system to prepare monthly and year-to-date summary tabulations.

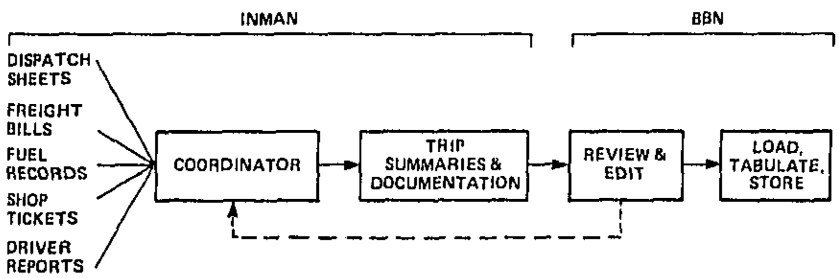

FIG. 6. REPORTING PROCEDURES.

Operations and Maintenance Information Summary

Unit__________

Period covered in this summary:

Dates: __________ to __________

Mileage: __________ to __________

Trip Segments

Date	Origin	Destination	Payload (lbs.)	GVCW
To				
To				
To				
To				
To				
		Average →		

Fuel Consumption __________ **gallons**

Fuel Economy __________ **MPG**

Maintenance

	Service 1	Service 2
Date		
Ticket No.		
Total Cost		
Noise Cost		
Down Hours		
Oil Analysis		

Attached Documents (check)

Freight bills __________

Fuel records __________

Driver reports __________

Shop tickets __________

Shop ticket addendum __________

Prepared by:

____

Date __________

FIG. 7. OPERATIONS AND MAINTENANCE INFORMATION SUMMARY.

Maximum reliance was placed on the operator's management reporting procedures and systems. Inman's maintenance reporting procedures were not designed to capture information on the noise treatments, particularly their impact on routine maintenance. A supplemental form, Shop Ticket Addendum, was designed and supplied to Inman to provide information on the number of times each noise control panel was removed or restricted access -- i.e., got in the way. The Addendum is presented in Fig. 8.

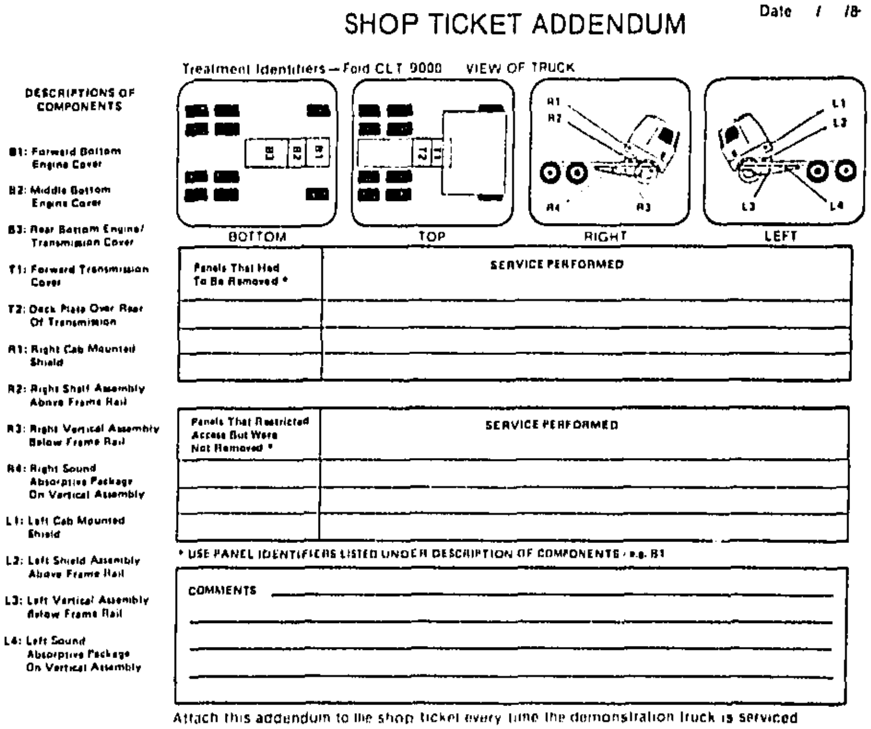

FIG. 8. SHOP TICKET ADDENDUM.

3.2 Chronology of Field Test Operations

The formal field test began on February 1, 1980 and continued through January 19, 1981. Major events during the field test and post-test evaluation period are summarized below, along with the date and odometer reading for each event. As indicated by the odometer reading, the truck already had accumulated over 30,000 miles prior to the field tests. These miles were accumulated by Inman during an earlier "break-in" period and during the development and installation of the noise control treatments.

1/20/80 33,930	Vehicle undergoes pre-service inspections, maintenance, and shake-down runs by Inman.
2/1/80 35,136	Formal field test begins.
3/5/80 40,714	BBN visits Inman facility to inspect vehicle and discuss field test procedures. Time and motion study conducted for removal and reinstallation of bottom panels.
3/16/80 43,678	Driver reports transmission oil heating to 225° to 230°F.
4/19/80 56,599	Driver reports transmission oil heating to 275°F.
5/9/80 66,458	Right front steering tire is cut by upper side panel R1.
5/20/80 72,892	Second report of damage to right front steering tire by panel R1. Damaged R1 panel repaired by Inman. BBN directs Inman to remove panels B1, B2, B3, and T1 and operate vehicle without the panels until transmission oil temperature tests can be conducted.
7/22/80 95,040	BBN team visits Inman in Tulsa. Inspects panel R1 and recommends new repairs. Truck instrumented and tested for impact of enclosure on transmission oil temperature.
7/31/80 96,340	Truck arrives in Sandusky for EPA noise tests.

9/8/80 97,943	Truck returns to Inman. Numerous repairs made in accordance with BBN instructions.
12/15/80 139,187	Driver reports upper side panel R1 is rubbing right front steering tire. Panel repaired by Inman.
1/19/81 147,675	Truck arrives in Sandusky for noise test prior to EPA Contractors' Briefing. End of formal field service test.
3/9/81 n.a.	MVMA tests - GMC Milford facility
3/19/81 n.a.	MVMA tests - Riverbank Acoustical Laboratory, Geneva, IL. Vehicle returned to Inman to replace Inman's aluminum wheels with original wheels.
5/1/81 149,468	Vehicle arrives at BBN, Cambridge, MA.

3.3 Mileage and Payload

The Ford CLT 9000 accumulated 107,201 miles in 12 months of supervised fleet service operations.* The monthly mileage of the vehicle is summarized in Fig.9 and Table 4. As the entries in the table show, the truck was used intensively. It logged 12,000 or more miles per month in 4 of the 12 months of service. The entries for February and August are anomalous. Mileage was not reported for several trips in February. August mileage is low because the vehicle was being tested at EPA's Sandusky noise facility. Average monthly mileage exclusive of these 2 months was 10,641 miles.

The monthly operations of the truck are summarized in Table 5. Its average trip length was in the thousands of miles and it was generally out on the road for more than a week at a time. Each trip consisted of several segments with a different load

*Odometer mileage from 2/1/80 to 1/19/81 was actually 112,539. We report on only those operations for which we have complete documentation. We exclude 5,338 miles for which documentation was not supplied.

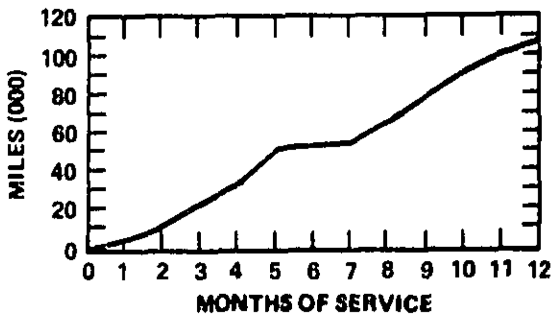

FIG. 9. CUMULATIVE MILEAGE.

TABLE 4. MONTHLY ODOMETER MILEAGE SUMMARY.

Month	Monthly Mileage	Cumulative Mileage
February	591	591
March	9,443	10,034
April	12,702	22,736
May	9,950	32,686
June	17,674	50,360
July	5,812	56,172
August	191	56,363
September	8,627	64,990
October	15,400	80,390
November	12,449	92,839
December	8,991	101,830
January	5,371	107,201

hauled on each segment. The payload entries in Table 5 show that the truck consistently hauled average payloads in the range of 39,000 to 43,000 lb. Gross vehicle combination weight (GVCW)

TABLE 5. MONTHLY OPERATIONS SUMMARY.

Month	No. of Trips	Average Trip (mi.)	Average Payload (lb)	Average GVCW (lb)
February	1	591	*	*
March	3	3,148	38,805	65,198
April	3	4,234	43,582	72,897
May	2	4,975	38,933	68,341
June	3	5,891	41,341	71,512
July	3	1,937	42,600	72,600
August	1	191	**	**
September	3	2,876	42,612	72,938
October	3	5,133	40,591	70,691
November	3	4,154	39,163	69,178
December	2	4,496	42,413	72,912
January	2	2,686	40,069	70,569

*Data were not reported.

**August data not meaningful since truck was undergoing tests and was not in normal service.

tends to range between 68,000 and 73,000 lb. There was no indication that the added weight of the noise treatments ever displaced payload.

The intensive use of unit 455 is evidenced by a comparison to other CLT 9000's in the Inman fleet. The fleet contained 110 CLT 9000's; 38 of these, units 417 to 454, were equipped with Caterpillar 3406 PCTA engines, the same as unit 455. Mileage and fuel economy data were obtained for these 38 comparison units.

Figure 10 and Table 6 present a comparison of the mileage of unit 455 to the comparison fleet. This information is derived from Inman's management information system reports and is different from the mileage estimates presented in Table 4. The Inman data in Table 6 are based on "route miles," a standard mileage between two locations. The BBN mileage estimates are based on actual odometer readings. This distinction accounts for the difference between the BBN and Inman estimates and also affects comparative fuel economy estimates presented in Sec. 5.2.

As shown in Table 6, the average CLT 9000 in the Inman fleet traveled 74,457 miles in the 10-month period April 1980 to January 1981. Unit 455 traveled 102,446 miles, or 38% above the fleet norm. Unit 455 was 1.22 standard deviations above the fleet average. The monthly entries show that in those months when the truck was in full service (i.e., not down for testing or repairs), it operated much more intensely than the average CLT 9000. For example, in June 1980 it traveled 17,875 miles in comparison to the 7,729-mile fleet average, or 131% above average. The intensity of use is also apparent in Fig. 10. In assessing these comparisons, the reader should keep in mind that the estimates for unit 455 include the July, August, and September period when the truck was partially out of service for testing or repairs.

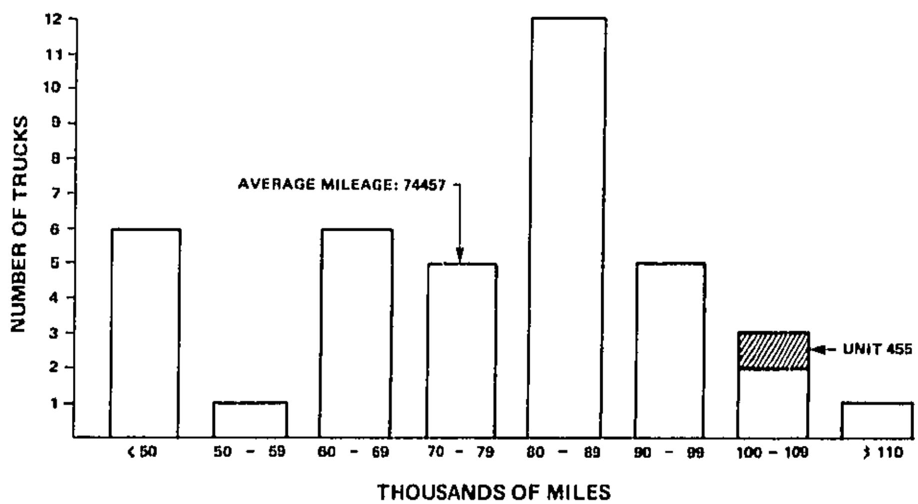

FIG. 10. DISTRIBUTION OF COMPARATIVE TRUCK MILEAGE.

TABLE 6. COMPARATIVE ROUTE MILEAGE FOR THE NOISE-TREATED FORD CLT 9000 AND COMPARISON FLEET.

	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Jan.	Total Period
Unit 455†											
Route Mileage	14,158	9,819	17,875	5,165	103	6,461	18,023	12,551	11,934	6,377	102,446
Comparison Fleet*											
Miles/Vehicle											
- Average	8,849	7,770	7,729	7,115	8,487	8,529	10,709	7,843	9,348	7,583	74,457
- Stand. Deviation	2,817	2,953	3,084	2,979	2,455	2,294	2,242	2,887	3,618	3,437	22,601
- Minimum	3,161	2,347	1,007	651	3,890	4,624	5,220	1,557	78	78	22,879
- Maximum	15,649	14,454	14,160	13,602	11,912	13,720	14,301	13,386	14,293	15,400	110,801

*Includes units 417 through 454. Monthly estimates exclude entries when a truck was not in service during the month or when entries are anomalous. The total period estimate includes all monthly entries for all trucks, including those not in service. Therefore, the total period estimate is not equal to the sum of the monthly entries.

†Entries for unit 455 are from Inman's Information System and do not correspond to BBN estimates. See text for discussion of reporting differences.

4. TREATMENT EVALUATION

One major purpose of the operational test was to evaluate the effectiveness and durability of the treatments. Here we discuss changes in noise level, durability of treatments, and a reported transmission overheating problem.

4.1 Noise Level Changes

Noise levels were measured before the truck entered service, approximately midway through its service, and after it left service. Table 7 summarizes the data acquired at these intervals. The data cover a range of 1.9 dBA over 17 months and 115,000 miles. The slight reduction in level during the first part of the test is probably not statistically significant. Variations on the order of 0.5 dBA may be ascribed to variations among test sites and instrumentation. The 1.7-dBA increase from the first to the last test appears to be significant, since the site was identical in both cases, and the differential level seems too large to be attributed to instrumentation differences.

TABLE 7. EXTERIOR NOISE LEVELS MEASURED BEFORE, DURING, AND AFTER THE OPERATIONAL EVALUATION.

Date	Odometer Reading	Location	40 CFR 205 Level (dBA)
Dec. 4, 1980	32,000 (approx.)	BBN - Cambridge	72.3
Dec. 10, 1979	N/A	EPA - Sandusky	72.6
Aug. 13, 1980	96,565	EPA - Sandusky	72.1
May 19, 1981	149,500	BBN - Cambridge	74.0

While the truck was at EPA's facility in August, EPA measured the noise level with various combinations of bellypan covers in place. The results, shown in Table 8, illustrate that removing the large rear cover creates the greatest rise in noise level, and that all three covers are indeed needed to enable the vehicle to approach most closely the 72-dBA goal.

TABLE 8. NOISE LEVELS WITH VARIOUS COMBINATIONS OF BELLYPAN COVERS IN PLACE.

Cover Condition			
B1 Forward Bottom Engine Cover	B2 Middle Bottom Engine Cover	B3 Rear Bottom Engine/ Transmission Cover	40 CFR 205 Level (dBA)
On	On	On	72.1
Off	On	On	72.8
Off	Off	On	73.4
On	Off	On	73.5
On	Off	Off	75.2
On	On	Off	74.5
Off	On	Off	75.0
Off	Off	Off	75.7

4.2 Component Durability

When the vehicle returned to BBN after its operational evaluation, it was meticulously inspected to evaluate the durability of the treatments that were installed. Overall, the treatments held up well. The major exceptions were the right side shield, (R1), which was deformed by interference from the right front tire, and the rubber strips installed in the rear spring brackets to eliminate clatter.

Figure 11 shows a rear view of the dual exhaust system. As may be seen from this figure, no degradation is apparent. Closer

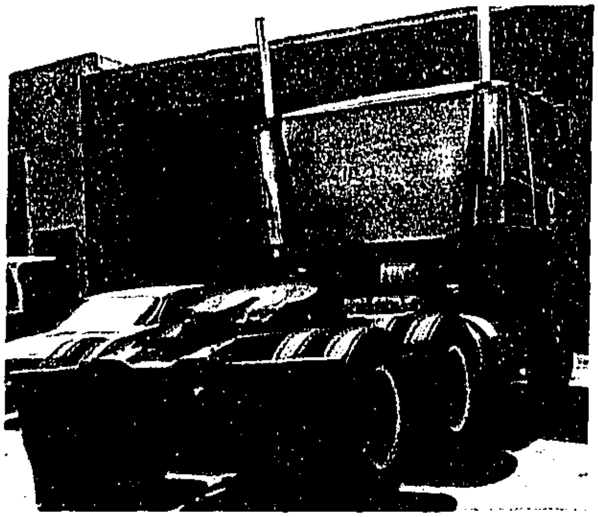

FIG. 11. DUAL EXHAUST SYSTEM.

inspection of the exhaust system components showed them to be in good condition.

A partial deterioration of the undercab sound-absorptive material, originally installed by the vehicle manufacturer, may be seen in Fig. 12. Two of the foam panels, faced with aluminized polyester, apparently fell off. On a third panel, the protective polyester covering has worn through, but no excessive absorption of oil or grime is seen. Maintenance records do not indicate when this deterioration occurred.

Figure 13 illustrates some of the damage that was done to the right side shield when it was struck by the right front tire. The shield was bent considerably more than the figure shows, but it was repaired shortly after the damage occurred.

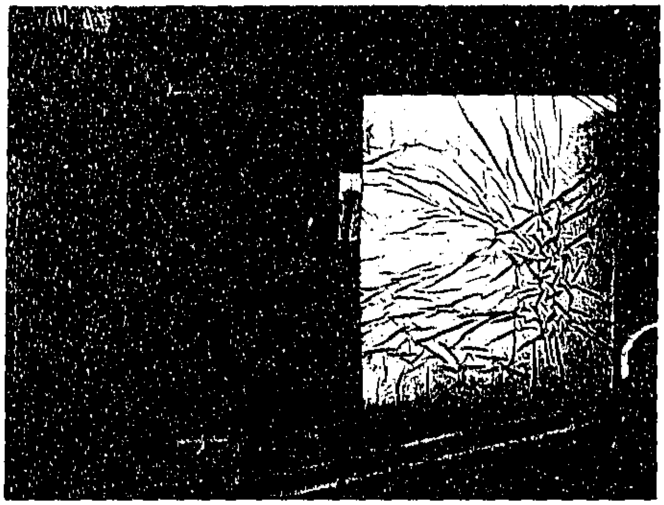

FIG. 12. PARTIAL DETERIORATION OF THE FORD UNDERCAB ABSORPTIVE TREATMENT.

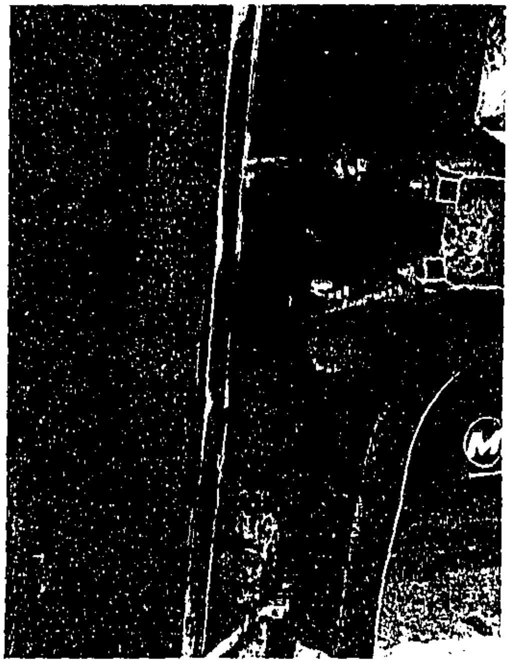

FIG. 13. DAMAGED RIGHT SIDE SHIELD.

This mishap demonstrates that there was insufficient clearance between shield and tire in the prototype installation. Clearly, more space should be allowed if the treatment is to be upgraded.

The vehicle is not constructed symmetrically and the left side shield is further inboard than the right shield. Figure 14 shows that the left shield was not damaged during the operational test.

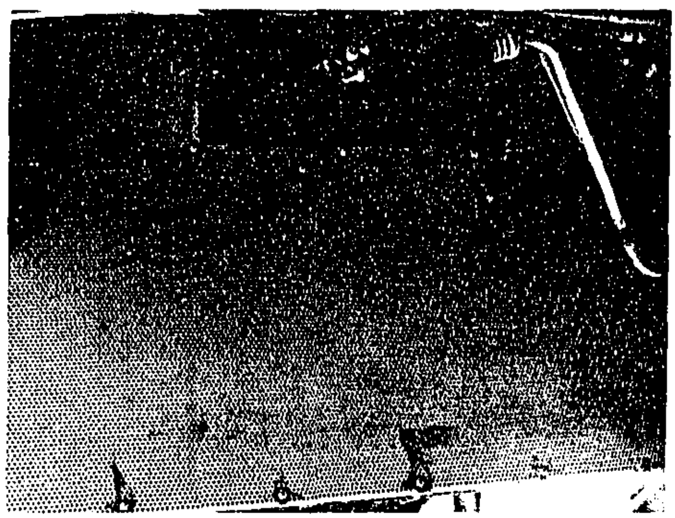

FIG. 14. UNDAMAGED LEFT SIDE SHIELD.

A closer view of the left shield shows that a strip about 3 in. wide along the bottom edge of the shield has been polished and left shining by the neoprene wiping seal (Fig. 15). The heads of the sheet metal screws used to fasten the perforated metal are clearly visible in this photograph. Figure 16 shows that these screw heads wore grooves in the left wiping seal. The right wiping seal exhibits even more wear, as illustrated in Fig. 17.

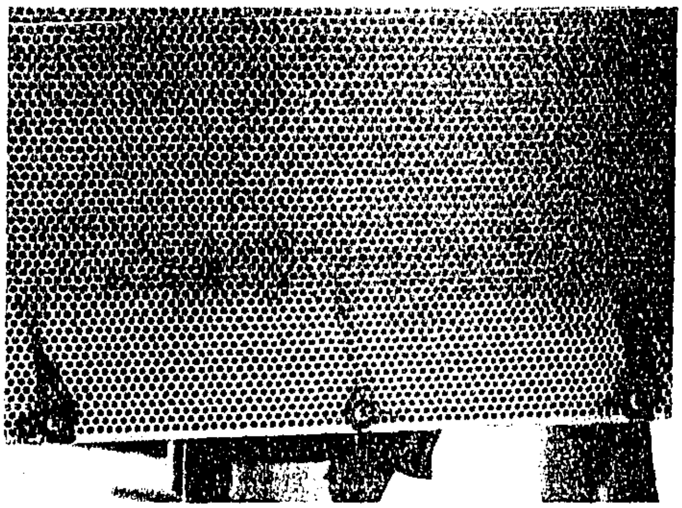

FIG. 15. LEFT SIDE SHIELD POLISHED BY NEOPRENE WIPING SEAL.

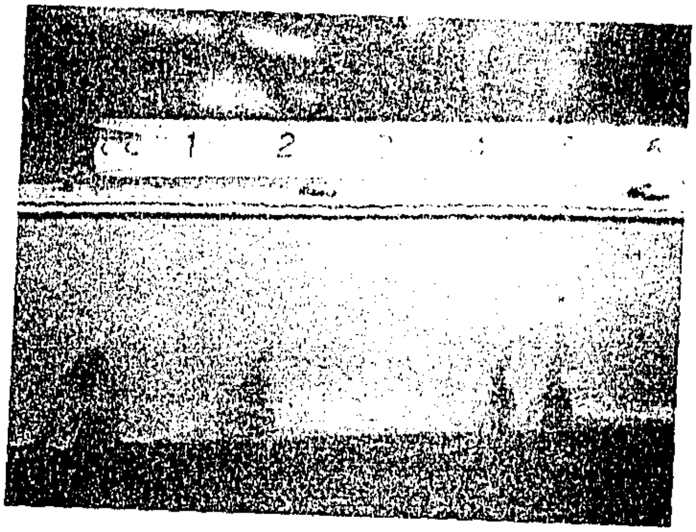

FIG. 16. WORN LEFT WIPING SEAL.

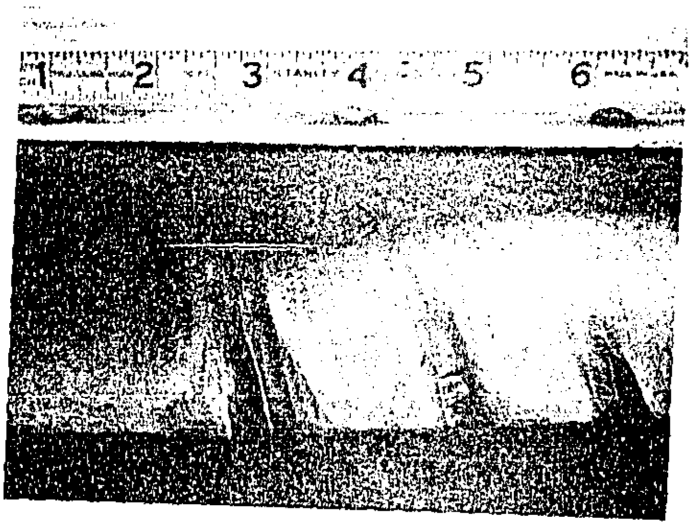

FIG. 17. WORN RIGHT WIPING SEAL.

The wiping seals are attached to shelves that proved very durable. There was slight damage to the right shelf, as illustrated in Fig. 18. The turbocharger and oil dipstick tube evidently impacted or rubbed the shelf to form the dents shown. Here too, additional clearance space would be required in a more advanced design.

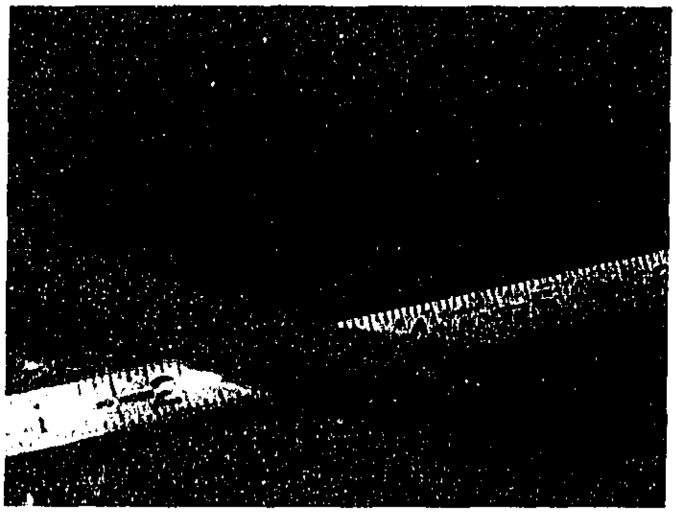

FIG. 18. SLIGHT DAMAGE TO RIGHT SHELF.

The transmission cover held up well during the test. Figure 19 shows the rear and forward portions of the cover. Two of the upper cover brackets are illustrated in this figure. A close-up of the left bracket (Fig. 20) shows that it is intact. A similar view of the right bracket in Fig. 21 shows a gap where a shim had apparently not been reinstalled after servicing.

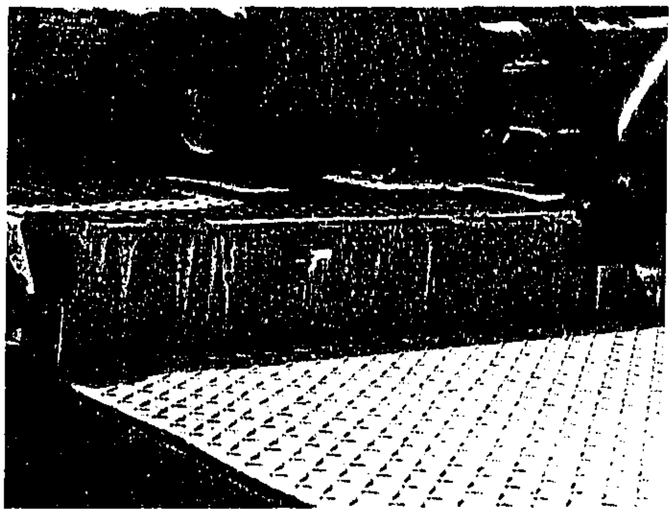

FIG. 19. REAR AND FORWARD PORTIONS OF THE TRANSMISSION COVER.

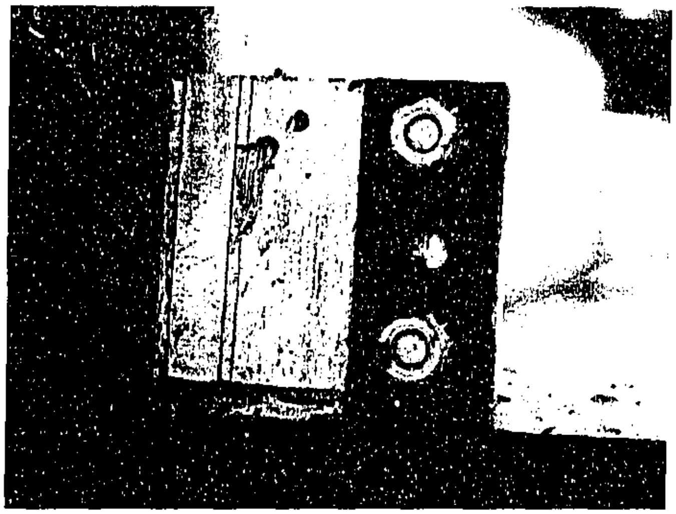

FIG. 20. LEFT TRANSMISSION COVER BRACKET.

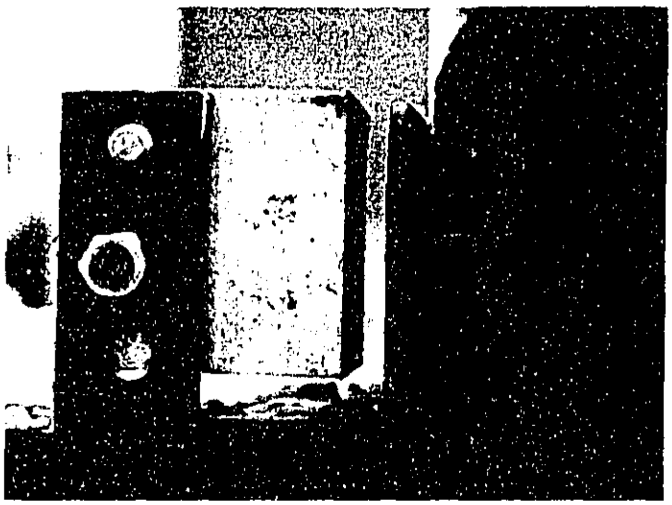

FIG. 21. RIGHT TRANSMISSION COVER BRACKET.

Figure 22 illustrates some problems that developed with the latches on the bottom engine covers. The latch at the left did not align properly with the keep and remained unfastened. The bail was missing from the right latch and was replaced by ordinary wire.

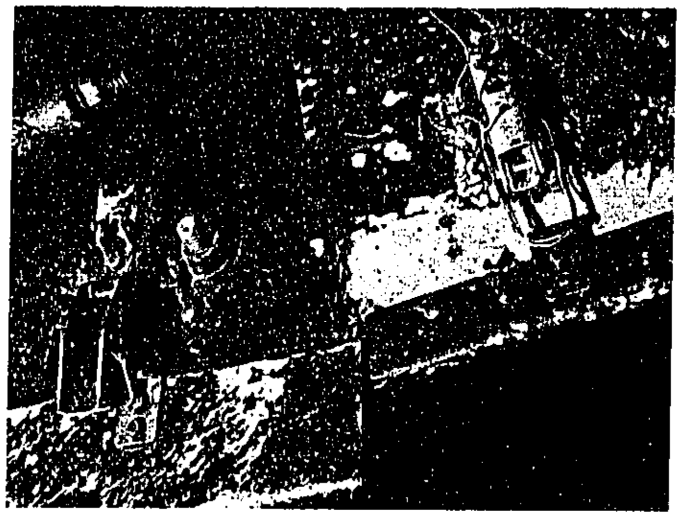

FIG. 22. FAULTY LATCHES ON THE BOTTOM ENGINE COVERS.

The cover for the oil filter access port had been held closed with a quarter-turn fastener, which used to pass through the hole visible at the left in Fig. 23. Apparently this fastener was lost and the cover swung open while the axle and spring were moving upward. The U-clamp on the spring engaged and severely bent the cover.

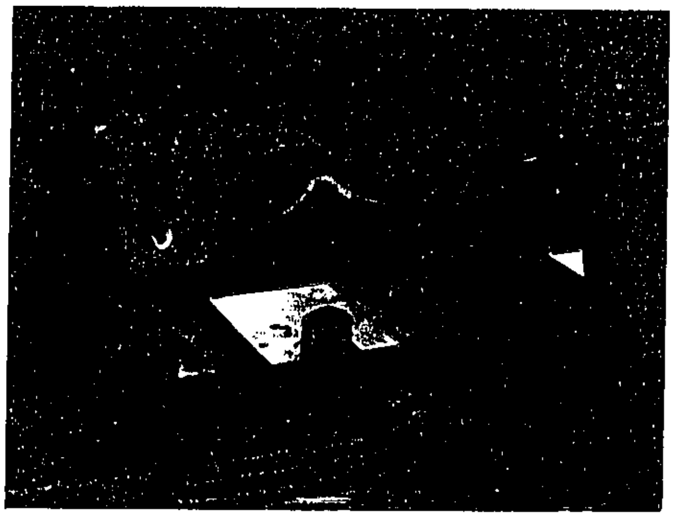

FIG. 23. MISSING QUARTER-TURN FASTENER ON OIL FILTER ACCESS PORT COVER.

Finally, Fig. 24 shows that the rubber placed between the rear spring and spring bracket did not last. The load and sliding action between the spring and bracket caused the rubber to fail and be pushed out of the intervening space.

In summary, the treatments proved to be effective and durable. The problems identified above were all of a relatively minor nature and were typical of prototype design and installation.

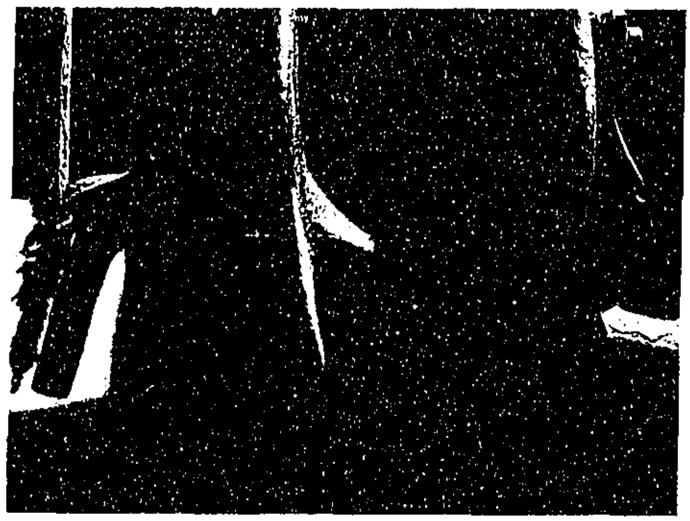

FIG. 24. DAMAGED RUBBER BETWEEN REAR LEAF SPRING AND REAR SPRING BRACKET.

4.3 Transmission Heating

On several occasions, the driver reported transmission overheating problems; the transmission oil temperature reached 275°F for extended periods. This level exceeds the 250°F level specified by the manufacturer. Sustained operation at that temperature could lead to oil failure. We were concerned that the acoustical enclosure might be causing this problem. Moreover, there were reports that the clutched fan was not operating properly, which could have compounded the problem.

To determine the transmission temperature and diagnose the nature of the problem, we equipped the truck with laboratory-grade instrumentation and conducted tests during a heat spell in Oklahoma in July of 1980. Measurements were made of the ambient air temperature, fan air temperature, fan rpm, and transmission oil temperature. We used standard-type "T" thermocouple junctions and recorded the data with a Monitor Labs datalogger, which included an electronic zero-point reference and thermocouple linearization. Total system accuracy was ± 0.2°F.

The fan rpm was recorded optically using a standard automotive 30-watt incandescent light mounted on the engine block, a slightly convex mirror mounted on the far (radiator) side of the fan, near the blade tip, and a directive photodiode detector exposed to chopped illumination, pointing at the mirror. We calibrated with a precision counter and used the computational capability of the datalogger to calculate rpm. System accuracy is estimated to be within a few percent.

Two road tests were conducted. Test 1 involved measurements of all parameters during a trip from Tulsa, Oklahoma, to Oklahoma City. For this test all acoustical treatment was in place and the truck pulled a loaded trailer. Gross combination weight was

68,340 lb. Test 2 was the return trip with an empty trailer and all acoustical panels* removed.

Figure 25 shows the fan speed as a function of time from the start of the outbound test. The fan is activated occasionally but spends most of the time idling at about 700 to 800 rpm. Figure 26 shows ambient, fan outlet, and transmission oil temperatures vs time. The ambient was 97.5°F at the start of the trip, reached a low of 92.7°F, and ended at 96.1°F. The transmission oil temperature required about 3 hours to reach a peak of 219°F and ended at 215.1°F. The fan outlet temperature ranged primarily from about 110°F to 170°F. The peak transmission oil temperature of 219°F is safely below the 250°F specification and well below the reported 275°F.

Figure 27 is a graphical summary of the return trip (Test 2) showing ambient, fan, and transmission oil temperatures. The transmission oil temperature stabilized at about 177°F, at an ambient temperature of about 88°F, and at a fan air temperature of 135°F.

In order to facilitate comparison of the data, we have computed the mean and standard deviation of each temperature. The results are shown in Table 9.

In a worst-case comparison, with acoustic panels in place, under load, in a heat spell, the maximum transmission oil temperature was about 217°F. This temperature was 40°F warmer than that for an unloaded truck, operating without acoustical panels, in an environment that was 8°F cooler ambient, and 19°F cooler behind the radiator (presumably because of a lighter load and

*These are B1, B2, B3, T1, and T2, illustrated in Fig. 8.

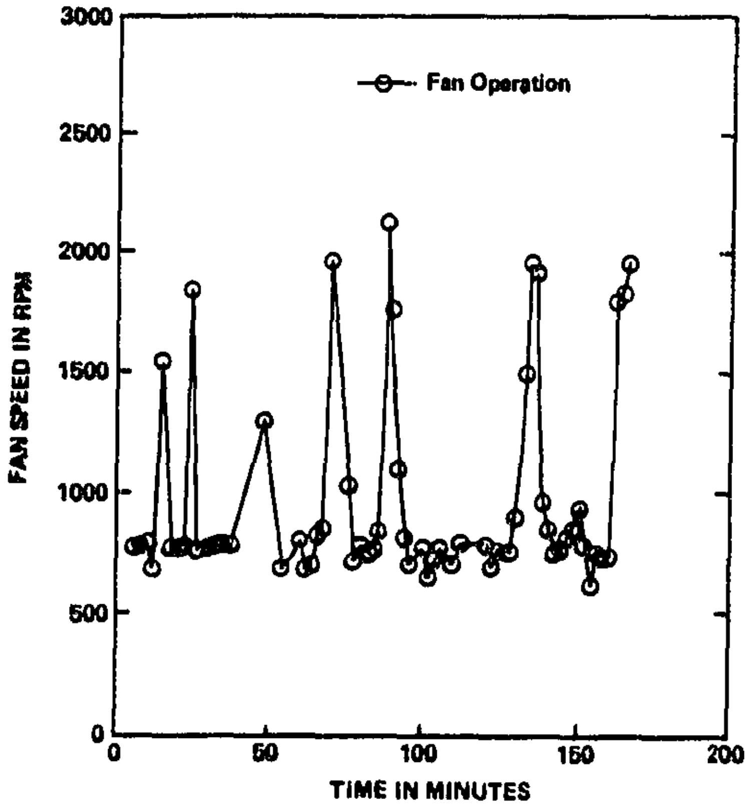

FIG. 25. ROAD TEST OF FORD CLT 9000 WITH ACOUSTICAL PANELS.

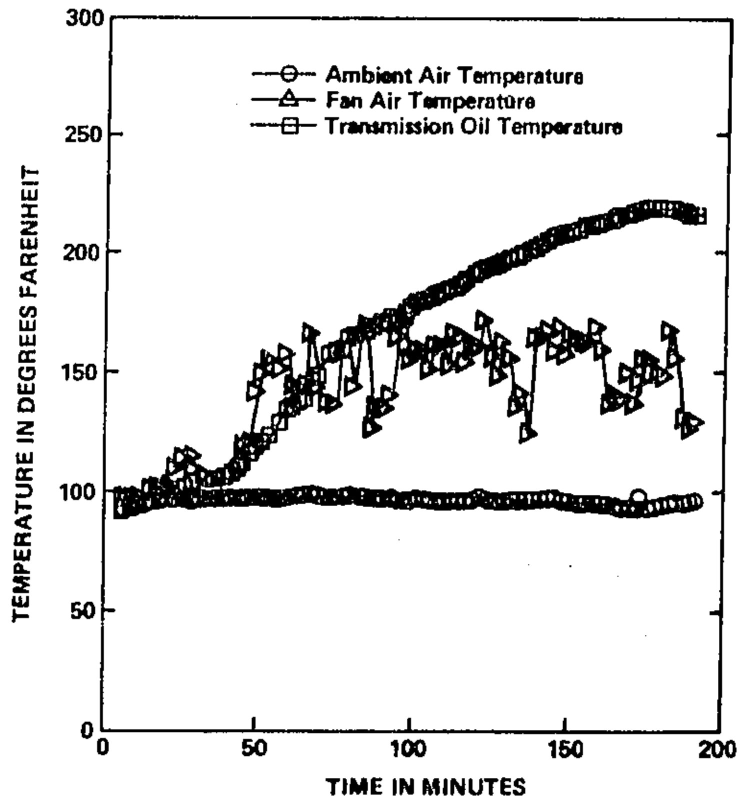

FIG. 26. TEMPERATURE TESTS OF FORD CLT 9000 WITH ACOUSTICAL PANELS.

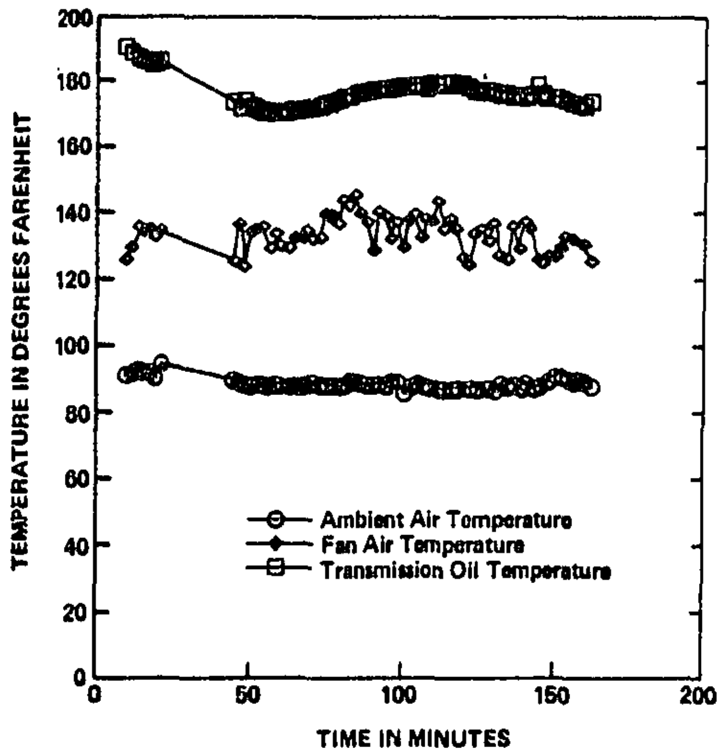

FIG. 27. ROAD TEST OF FORD CLT 9000 WITHOUT ACOUSTICAL PANELS.

TABLE 9. SUMMARY OF TRANSMISSION HEATING TEST RESULTS.

Test	Ambient Air (°F)		Fan Air (°F)		Trans. Oil (°F)	
	Mean.	Std. Dev.	Mean.	Std. Dev.	Mean.	Std. Dev.
Test 1 Acoustical Panels Load	96.5[1]	1.6	152.5[1]	12.6	217.2[2]	1.3
Test 2 No Panels No Load	88.4[3]	1.2	133.6[3]	5.5	177.8[3]	2.0

[1]Data from minutes 54 through 192 (last 140 minutes).
[2]Data from minutes 174 through 192 (last 20 minutes).
[3]Data from minutes 79 to 163 (last 86 minutes).

less thermal demand). If we adjust for this 19-degree differential in radiator exhaust (fan) air temperature, we find that the transmission oil temperature was about 21°F warmer as a result of the acoustic panels in this severe test.

We conclude that the engine and transmission enclosure was not the cause of the 275° transmission oil temperature. The test results show that while the enclosure did increase the oil temperature, the increase was well within the manufacturer's specification.

We cannot pinpoint the cause of the reported overheating problem. We were unable to check the accuracy of the cab gauge during the test because the temperature probe for the gauge had to be removed from the transmission in order to insert the test probe. Oil analysis reports received from Inman's laboratory never indicated any deterioration of the transmission oil, even during the period when the 275° temperature was reported.

5. FUEL ECONOMY

Several aspects of the noise control treatment may contribute to changes in vehicle fuel economy. The increased weight associated with the dual exhaust system and the engine/transmission enclosure adds to the rolling resistance which, in turn, results in the need for a greater energy expenditure to haul a given load. The enclosure may either reduce or increase aerodynamic drag, which will similarly affect fuel consumption. The backpressure generated by the exhaust system will influence engine efficiency and associated fuel consumption.

Here we examine these effects in two stages. First we will estimate the magnitude of the effects of noise treatment on fuel consumption; then we will analyze field data in an attempt to determine the actual impact.

5.1 Anticipated Treatment Effects

To estimate the additional fuel cost associated with additional weight, we consider the approximate relation between fuel consumption and weight presented in Fax and Kaye [6]. Using a least squares regression technique, Fax and Kaye [6] fit a straight line to field data from a range of operations to derive the average fuel consumption sensitivity of

$$\Delta GPM/\Delta GCW = 1.45 \times 10^{-6} \text{ gal/mile/lb} ,$$

where ΔGPM is the incremental fuel consumption in gal/mile and ΔGCW is the incremental gross weight.

The total weight increase associated with the noise treatment is 397 lb [1]. Using this value in the above equations gives an expected change in fuel consumption of 5.76×10^{-4} gal/mi. This represents 0.215% of the fuel consumption of 0.268 gal/mi determined from the field test.*

To estimate the effect of backpressure, consider the relationships between fuel efficiency and backpressure illustrated in Fig. 28. The shaded area corresponds to a published composite of data [7], while the three curves within this area are for proprietary data supplied to BBN by several engine manufacturers. Reference 7 suggests that fuel economy improves by an average rate of 0.5% per inch of mercury decrease in backpressure. This number is consistent with the data in Fig. 28 and will be used for our estimates.

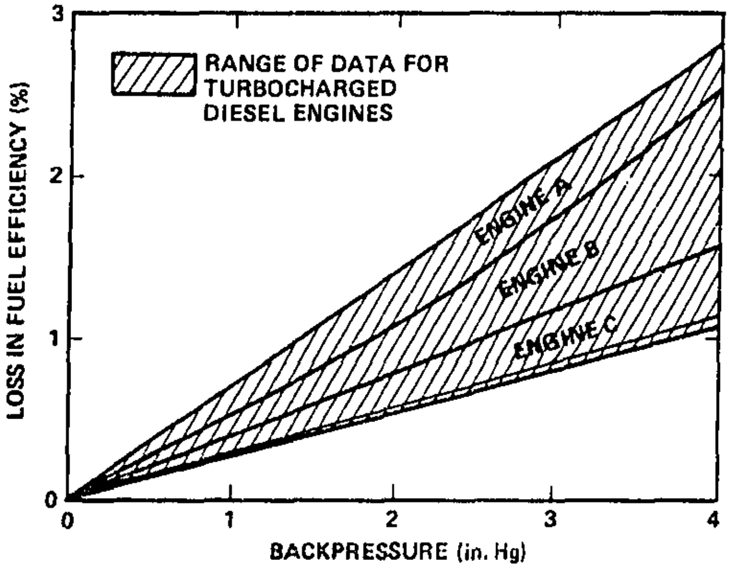

FIG. 28. RELATIONSHIP OF DIESEL ENGINE FUEL EFFICIENCY TO EXHAUST BACKPRESSURE.

*See Table 10.

The backpressure generated by the original and final exhaust systems, measured under laboratory conditions on a Caterpillar 3406 DIT engine rated at 280 HP, were 1.75 in. Hg and 1.5 in. Hg respectively. That engine had an exhaust flow of 2000 cfm at a density of 0.0307 lb/ft^3; whereas the quieted truck PCTA engine at 340 hp had an exhaust flow rate of 2200 cfm and a density of 0.0298 lb/ft^3. Since pressure drop is proportional to density times the square of the volume flow rate, the values corresponding to the DIT engine must be adjusted upward by $(0.0298/0.0307) \times (2200/2000)^2 = 1.17$. Thus the reduction in fuel consumption owing to the lower backpressure of the final system is expected to be $1.17(1.75-1.5)(0.5) = 0.146\%$.

Aerodynamic effects are not readily estimated on the basis of existing data. Wind tunnel tests of the vehicle or an accurate scale replica would be required to determine changes in drag, and such tests are beyond the scope of this program.

In summary, the anticipated effects of noise control treatments are:

	Increase <Decrease> in Fuel Consumption
Weight	0.215%
Backpressure	<0.146>
Net	0.069%

5.2 Field Data Analysis

BBN estimates the fuel economy of the Ford CLT 9000 to be 3.738 mpg during the twelve months of service.* As the Fuel

*This estimate is based on 105,030 miles and 28,097 gallons of fuel. It excludes 2,171 miles for which BBN could not verify fuel consumption: 591 miles in February; 1,389 miles in July; and 191 miles in August.

(mpg) column in Table 10 shows, the vehicle's fuel economy generally ranged between 3.73 and 3.95 mpg. The only significant variation was in December and January, when fuel economy dropped to approximately 3.2 mpg. Source documents for December and January do not indicate any changes in operation or payload that would explain such a marked decline in fuel economy.

The BBN estimates of fuel economy presented in Table 10 are based on actual odometer miles and fuel records reviewed by BBN. We exclude from these fuel economy estimates trips where we could not verify actual fuel consumption from a fuel record source document. The BBN fuel economy estimates also differ from Inman estimates presented below. Inman bases its mileage on "route" miles, whereas BBN uses actual odometer readings. The BBN estimates are based on actual fuel consumption, whereas the Inman estimates are based on fuel bills. Delays in processing the fuel bills and in allocating the fuel charges can affect the Inman estimates.

Table 11 presents Inman estimates of comparative fuel economy for Unit 455 and the 38 comparison vehicles in the Inman fleet. Figure 29 presents a graphic comparison of the quiet unit and the comparison fleet. Unit 455 achieved overall fuel economy of 3.78* miles per gallon vs 3.83 miles per gallon for the comparison fleet. This differential of 0.05 miles per gallon represents 1.3% lower fuel economy for the quieted truck. This 0.05 miles per gallon differential is much less than the standard deviation for miles per gallon in Table 11.

While the comparison fleet has the same Caterpillar engine as Unit 455, there are differences between the quieted unit and

*This estimate is based on 102,466 route miles and 27,075 gallons of fuel.

TABLE 10. OBSERVED FUEL ECONOMY - BBN ESTIMATE.

Month	Mileage	Fuel (gal)	Fuel (mpg)
February	*	*	*
March	9,443	2,504	3.771
April	12,702	3,276	3.877
May	9,950	2,513	3.959
June	17,674	4,490	3.936
July	4,423†	1,184†	3.736†
August	**	**	**
September	8,627	2,295	3.759
October	15,400	4,041	3.811
November	12,449	3,332	3.736
December	8,991	2,768	3.248
January	5,371	1,694	3.171
Total	105,030	28,097	3.738

*Data were not reported.

†Fuel consumption and fuel economy (mpg) are reported for only 1 of 3 trips; fuel consumption for a test trip in Tulsa and the trip to Sandusky were not reported.

**August data not meaningful since truck was undergoing tests and was not in normal service.

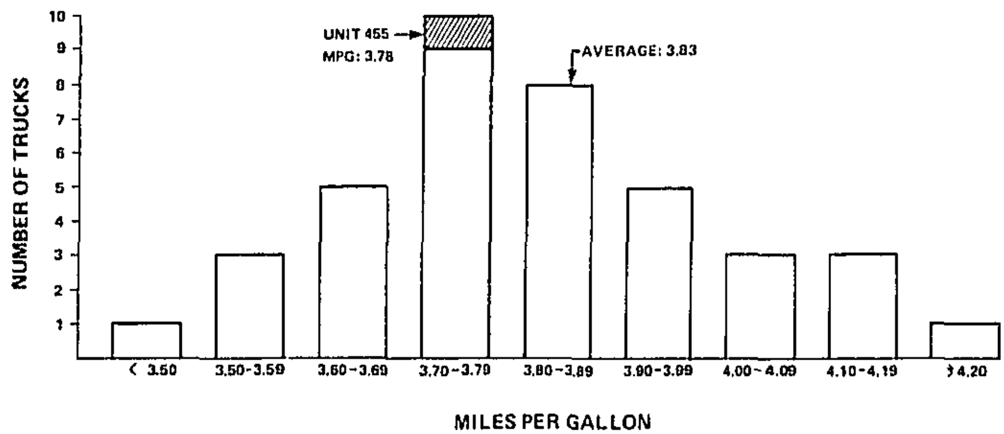

FIG. 29. DISTRIBUTION OF COMPARATIVE FUEL ECONOMY.

TABLE 11. COMPARATIVE ROUTE MILEAGE FUEL ECONOMY FOR THE NOISE-TREATED FORD CLT 9000 AND COMPARISON FLEET.*

	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Jan.	Total Period
Unit 455†											
Miles/Gal.	3.47	3.90	4.16	3.91	4.12	3.60	3.83	3.75	3.95	3.24	3.78
Comparison Fleet*											
Miles/Gal.											
- Average	3.82	4.06	3.97	4.18	3.86	3.96	3.84	3.69	3.78	3.25	3.83
- Stand. Deviation	0.52	0.74	0.67	0.87	0.77	0.53	0.39	0.83	1.17	0.91	0.20
- Minimum	2.08	2.33	2.79	2.86	2.81	2.82	2.98	1.96	3.05	2.05	3.50
- Maximum	4.80	6.03	6.86	6.60	7.62	5.50	4.80	6.14	6.55	4.95	4.32

*Includes Units 417 through 454. Estimates exclude entries when truck was not in service during the month or when entries are anomalous.

†Entries for Unit 455 are from Inman's Information System and do not correspond to BBN estimates. See text for discussion of reporting differences.

the comparison fleet that can affect fuel economy. The comparison fleet is set to 375 hp at 2100 rpm. The quieted unit was set at 340 hp at 1,950 rpm but subsequently was uprated by Inman to 375 hp at 2100 rpm. The comparison fleet has a 3.90 rear end ratio, while the quiet unit has a 4.33 ratio. Finally, the comparison fleet was equipped with Spicer 7-speed transmissions, while Unit 455 had a Fuller 13-speed transmission. This latter difference probably had a negligible impact on fuel economy, since the vehicles operate in their top gear most of the time.

6. MAINTENANCE

The noise control treatments may increase truck maintenance requirements through:

- the need to remove and replace panels used for noise treatment
- restricted access to components requiring service
- degradation of the treatments themselves.

Here we discuss some of the effects of noise treatments on maintenance and present an analysis of data acquired during the field operational test.

6.1 Treatment Effects

Much of the truck maintenance is performed from a service pit under the vehicle. To access major drive train service points (e.g., lubrication fittings), it is necessary to remove and replace panels as illustrated in Fig. 30. The time required

FIG. 30. REMOVAL OF BELLYPAN PANELS.

to remove and replace bellypan panels from a grease pit was measured. First, a mechanic removed the panels to familiarize himself with the location of latches, etc. Then he was timed as he installed and removed them. He was instructed to work at a normal pace. Table 12 shows the time spent on this operation:

TABLE 12. TIME REQUIRED TO REMOVE AND INSTALL BOTTOM PANELS.

	Remove Panel	Install Panel
Front (B1)	17 sec	25 sec
Middle (B2)	18 sec	45 sec
Rear (B3)	47 sec	2 min 25 sec
Total	1 min 22 sec	3 min 35 sec

Once the panels are removed, drive train components are reasonably accessible. Figure 31 shows a mechanic beneath the

FIG. 31. REMOVAL OF ENGINE OIL PLUG.

truck removing the engine oil plug. In Fig. 32 the mechanic is lubricating a U-joint, the fitting for which happened to stop at the least convenient spot above the drive shaft. In neither case does the treatment appear to restrict access.

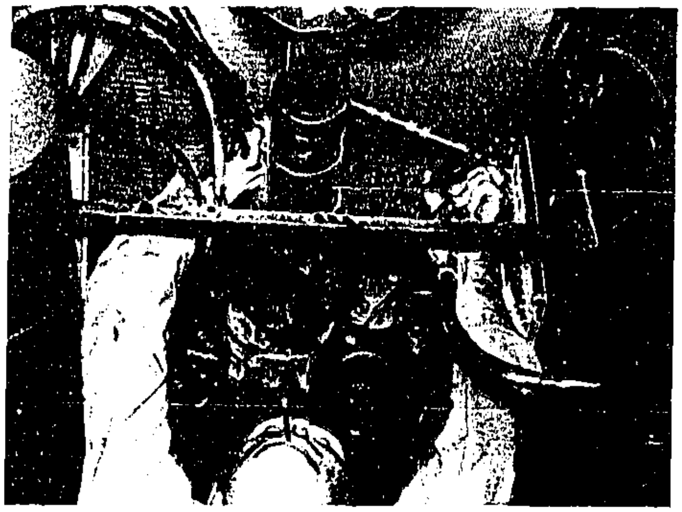

FIG. 32. LUBRICATION OF DRIVE SHAFT U-JOINT.

Figure 33 shows a filter wrench on the oil filter. The wrench is inserted through an access port in the right vertical assembly below the frame rail. When the filter is loosened, a mechanic reaches it from under the vehicle and removes it by hand. The procedure is reversed for filter installation. In this case, the treatment does limit access.

A common practice followed in servicing the truck is to tip the cab partway forward and set a lock on the tilt cylinder to prevent the cab from falling back on a workman. We believed that the presence of noise treatment components such as side shields could exacerbate the safety hazard of this procedure. Therefore, we decided not to use the procedure during the field test. Accordingly, the plaque illustrated in Fig. 34 was installed at the hydraulic tilt pump.

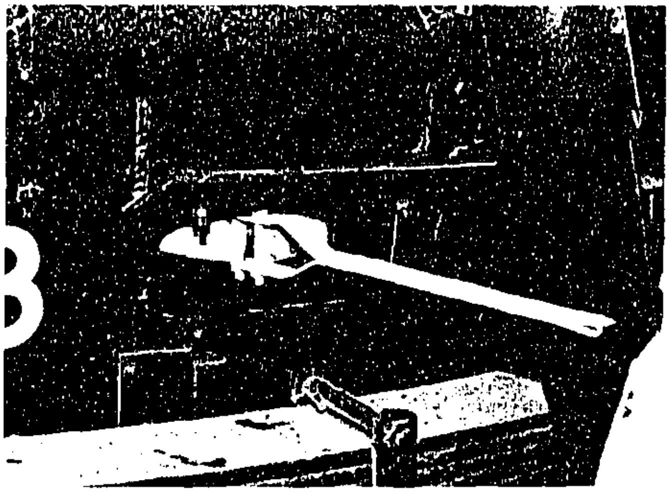

FIG. 33. OIL FILTER WRENCH INSERTED THROUGH ACCESS PORT IN ENCLOSURE.

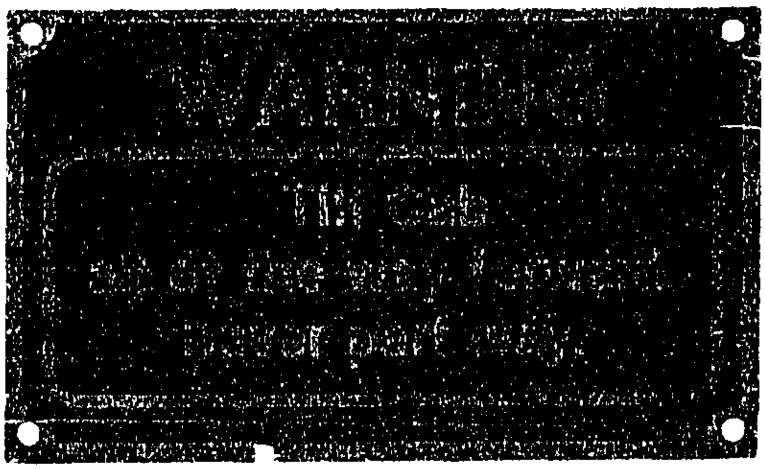

FIG. 34. WARNING PLAQUE.

6.2 Vehicle Maintenance Costs

The quieted Ford CLT 9000 accumulated $6,694.30 of maintenance costs in its year of service. Approximately 7.4% of this total is attributable to the noise control treatments installed on the vehicle. This section describes the maintenance experience of the truck during the field test. Major emphasis is placed on discussion of maintenance costs attributable to the noise control treatments. Appendix A presents a detailed summary of the specific maintenance performed on the truck.

Maintenance costs, for purposes of the field test, were divided into three categories:

- regular maintenance
- outside maintenance
- maintenance related to noise treatments.

Regular maintenance was performed on the truck by Inman at the Tulsa maintenance facility. Inman's policy is to perform as much maintenance as possible in its own shop to minimize use of outside repair facilities. The cost of regular maintenance was obtained directly from Inman shop tickets. The shop tickets describe the maintenance performed, the labor time for each maintenance item, and the parts and materials used. Labor costs were charged at Inman's internal labor rate of $17.00 per hour. This rate included an overhead factor. Parts and materials were charged at Inman's actual costs. The costs of outside repairs were obtained from invoices to Inman for the repairs performed.

Maintenance costs attributable to the noise control treatments include:

- costs of repairs to the treatments
- costs of repairs to other components caused by the treatments

- costs of removing and installing panels while servicing the vehicle.

These costs were obtained from the shop tickets and the accompanying Shop Ticket Addendum (see Fig. 8).

Table 13 presents an overall summary of maintenance costs for the Ford CLT 9000. Figure 35 shows cumulative costs over the 12 months, while Table 14 presents the monthly pattern of maintenance costs. The figure and tables provide a comprehensive overview of maintenance to Unit 455.

TABLE 13. SUMMARY OF CUMULATIVE MAINTENANCE COSTS.

Type of Service	Cumulative Cost
Regular	$5,661.33
Noise Treatment Related	
- repairs	457.35
- panel removal	42.98
Outside Repairs	532.64
TOTAL	$6,694.30

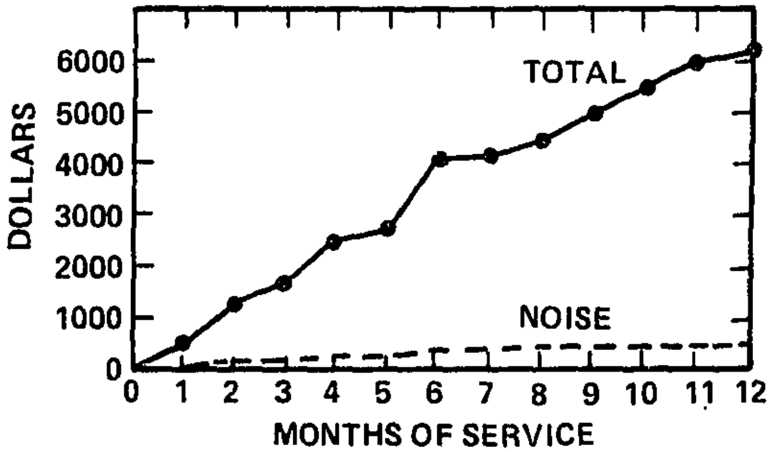

FIG. 35. CUMULATIVE MAINTENANCE COSTS.

TABLE 14. SUMMARY OF MONTHLY MAINTENANCE COSTS.

	Type of Service			Maintenance Cost	
Month	Outside	Regular	Noise	Monthly Total	Per Mile per Month
February	0.	439.13	0.	439.13	0.743
March	24.00	998.01	8.50	1,030.51	0.109
April	0.	332.17	0.	332.17	0.026
May	0.	800.74	51.0	851.74	0.086
June	49.30	202.21	0.	251.51	0.014
July	0.	1,238.51	291.26	1,529.77	0.263
August	0.	0.	0.	0.	0.
September	0.	218.41	102.0	320.41	0.037
October	10.0	597.63	0.	607.63	0.039
November	11.80	375.24	0.	387.04	0.031
December	0.	357.22	4.59	361.81	0.040
January	437.54	145.04	0.	582.58	0.066
Adjustment*		<42.98>	42.98	-	-
TOTAL	532.64	5,661.33	500.33	6,694.30	0.062

*Adjustment for incremental cost of removing panels during regular maintenance. Refer to discussion in text.

The regular maintenance of the vehicle was essentially routine. There were no large or extraordinary expenses during its year of operation. However, several minor problems recurred continually -- faulty air conditioner, fan clutch malfunctions, and problems with the tilt-cab hydraulic system. None of these problems had any relation to the noise treatments. Inman personnel indicated that these problems, particularly the air conditioner, were typical for their CLT 9000 fleet. Comparative maintenance cost data were not available. Inman discontinued its maintenance cost reporting system shortly after the field test started. BBN was not aware of this internal management decision by Inman until several months into the field test. There is, therefore, no basis for comparing the maintenance costs of Unit 455 to other vehicles in the Inman fleet. The only qualitative comparison that can be made, based on discussions with Inman personnel, is that there was nothing unusual about the regular maintenance of Unit 455 in comparison to other CLT 9000s in the fleet.

There were several instances of maintenance related to the noise control treatment. The major item was repairs to the right upper panel caused by its interference with the right steering tire. The prorated replacement cost of the tire damaged by the panel is also considered as treatment-related maintenance.

The costs associated with the repair of panel R1 can be seen in Table 14. The $51 charge for May is for 3 hours to straighten panel R1, remove and reweld the mounting bracket, and reinstall the bracket and panel. The $291.26 charge for July is the prorated cost of replacing the steering tires. The right steering tire had been cut in May by panel R1 and the charges appeared in July. Both steering tires were replaced and 50% of the cost was charged to maintenance related to noise control treatment. The $102 charge in September was for six hours of labor to make miscellaneous repairs to the treatments. The repairs were based on inspections of the truck by BBN and EPA at Tulsa in July and at Sandusky in August. The repair order from BBN to Inman included the following treatment-related items:

- The fasteners holding the front bellypan cover (B1) to the enclosure were not complete. A bracket spanning the width of the enclosure at the very front was missing. The bracket was replaced and three new fasteners were installed.
- The R1 panel was repaired. The lower aluminum channel, 1 3/8 x 3/4 x 1/8-in. thick and 66 1/4 in. long, was replaced and the solid aluminum and perforated metal sheet was reattached with sheet metal screws.
- The latches holding panel B3 to the enclosure on the left side of the truck were replaced.
- The perforated metal on the bottom side of the forward transmission cover was no longer attached. New holes were drilled and the perforated metal was reattached with sheet metal screws.
- The cross panel connecting both sides of the enclosure between panels B1 and B2 had two bolts missing. These were replaced, and all 4 bolts were properly tightened.

These repairs were made by Inman, and the truck returned to service. There were two other instances of treatment maintenance: $8.50 in March to correct interference of a panel with an air line; and $4.59 in December for a minor repair to panel R1.

Table 15 presents a summary of the number of times Inman reported that an individual panel was removed or restricted access while the vehicle was being serviced. The vehicle was serviced 36 times. Panels were removed on 14 of the 36 occasions

TABLE 15. SUMMARY OF PANEL REMOVAL, REINSTALLATION, AND ACCESS RESTRICTIONS.

Panel Identifier	Number of Times	
	Removed and Reinstalled	Restricted Access
B1	8	3
B2	6	2
B3	12	1
L1	0	1
R1	0	3
T1	2	0
TOTAL	28	17

on which the vehicle was serviced. Panels restricted access on 5 occasions while the vehicle was serviced. As is evident from the entries in Table 15, the bottom panels, B1, B2, and B3, were most frequently removed, while the upper panels, R1 and L1, were cited only as restricting access.

We define panel removal as the removal and reinstallation of a panel. This information is obtained directly from the shop ticket addendum. "Panel restrictions" are defined as panels that restricted access but were not removed during repair and maintenance operations. This category is intended to capture data on the extent to which panels "got in the way" while the vehicle was being serviced.

Table 12 presented in Sec. 6.1 reports the times required to remove and reinstall various panels. The times for panels B1, B2, and B3 are based on the actual time measured by BBN of an

Inman mechanic removing and then reinstalling each of these panels. The time required to remove and reinstall the top panel, T1, is 27 minutes. This time estimate is for a BBN technician measured at BBN's facility. These times can be used to estimate the incremental cost of regular service attributable to panel removal. Multiplying the number of times a panel was removed and reinstalled (from Table 16) by the corresponding time yields a total incremental time of 104 minutes and 18 seconds (104:18). The cost of this time at $17 per hour is $29.55.

The entries in Tables 12 and 15 can be used to estimate incremental maintenance costs attributable to access restrictions. We assume, as a worst case, that the time penalty for access restriction is not greater than the time to remove and reinstall the panel. The exceptions are panels R1 and L1. These panels are not designed to be removed for routine maintenance.

We reviewed the shop tickets and Shop Ticket Addenda that indicated panels L1 and R1 had restricted access. We found they restricted access during the following service tasks:

- replacing the compressor and servicing the air conditioner
- adding oil with the cab up
- changing the water regulator.

Given the nature of these tasks and the location of panels L1 and R1, BBN estimates that each job may have taken an extra 10 minutes. Therefore, we assign 10 minutes as an access restriction penalty for panels L1 and R1.

Given this access penalty and the times for panels B1, B2, and B3 in Table 12, the incremental time attributable to access restrictions can be calculated by multiplying the number of times a panel restricted access by the corresponding time. The total incremental time penalty for access restrictions is 47 minutes and 20 seconds (47:20). The cost at $17.00 per hour is $13.43.

The total incremental time costs associated with the noise control treatments are summarized below:

• Removal and reinstallation	$29.55
• Access restrictions	13.43
Total incremental cost	$42.98

The extra 2 hours and 32 minutes is 1.7% of the 147 labor hours of regular service charged by Inman.

The $42.98 estimate is based on information supplied by Inman and estimates by BBN. It is our best estimate of the incremental time attributable to the panels. The relatively small cost indicates that enclosures did not significantly increase maintenance labor costs.

7. SUMMARY AND CONCLUSIONS

The major quantifiable results of this operational evaluation are shown in Table 16. This table shows that the impact of the noise control treatment on readily measured parameters was small. The backpressure of the dual exhaust system was actually less than that for the original system. Normal maintenance costs associated with the noise treatment were only a few percent of overall maintenance costs for the vehicle. The impact on fuel consumption was an immeasureable 0.069%.

TABLE 16. SUMMARY OF QUANTIFIABLE TEST RESULTS.

Parameter	Change	
	Value	Percent
Noise Level	- 4.5 dBA	-
Back Presure	-0.25 in. Hg	-
Weight	397 lb	2.5% of tractor 0.5% of GCWR
Maintenance Cost - normal[1]	$ 42.98	0.7%
abnormal[2]	457.35	7.4%
Fuel Consumption[3]	18.68 gal	0.069%

[1]Includes intrinsic effects, such as interference of covers.

[2]Includes problems that could be corrected, such as tire and side shield damage caused by inadequate clearance.

[3]Predicted value is given. Actual value was immeasureable.

The issue of treatment durability extends beyond the measurable parameters presented in Table 16. Instances of component wear and failure have occurred in varying degrees, during the course of the operational evaluation. Many of these are clearly correctable according to the results of this test. The undercab sound-absorptive treatment could be more firmly fastened by using a better adhesive. The damage to the right side shield and right shelf could be avoided by redesigning these components with more clearance space for the tire, turbocharger, and dipstick tube. Wear to the wiping seals is perhaps more unsightly than acoustically detrimental and could be substantially reduced by using flush-mounted fasteners for the perforated metal on the side shields. Loss of the shim in the top transmission cover could be avoided by using brackets that fit better and do not require a shim.

Finding better ways to fasten covers requires some investigation. It may be that larger, more rugged side latches would suffice for the bottom panels and a more durable quarter-turn fastener would suffice for the oil filter access door. On the other hand, an alternate fastening arrangement may be necessary. This problem can be solved through an experimental development effort.

It is clear that the noise treatment for this truck does not represent a final design, but rather a possible first step in integrating noise control into vehicle design. All of our treatment was fabricated simply and added to an existing vehicle. Ultimately, if such treatment were to be manufactured in quantity, one would expect that alternate shapes and materials would be used. Plastics could replace aluminum and composite materials could replace the relatively elaborate build-up of absorptive panels. Constructing a single exhaust system providing nearly the performance of the dual system might be feasible. We believe that, in the end, weight and costs could be reduced without compromising environmental noise levels.

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APPENDIX A:

SUMMARY OF VEHICLE MAINTENANCE

Date	Description	Noise Control Cost (in dollars)	Total Cost (in dollars)
02/01/80	Installed mirror heater	-	190.22
02/18/80	Checked engine oil leak; replaced U-joint on transmission; replaced windshield; miscellaneous repairs and adjustments	-	229.91
02/21/80	Checked for oil leaks; tightened feed line and filler tube line	-	19.00
03/07/80	Miscellaneous inspections and repairs	8.50	80.28
03/12/80	Service items not indicated	-	59.33
03/16/80	On-the-road repair		24.00
03/18/80	Moved 5th wheel forward, welded to new angle iron; checked right front wheel seal; tightened fitting and added fluid to power steering pump; fixed cab jack	-	152.08
03/21/80	Service items not recorded	-	519.96
03/27/80	Checked driver's complaint of high fuel consumption and low power; replaced spacer; reset hi-idle to specs	-	194.86
04/02/80	Replaced manifold gaskets	-	68.00
04/04/80	Replaced back seal on front right end; replaced front seal on back right end; checked grease in gear box	-	39.71
04/14/80	Changed antifreeze; checked right cab jack ram for leak; adjusted clutch and brakes; tightened 2 water hose clamps;		

Date	Description	Noise Control Cost (in dollars)	Total Cost (in dollars)
	adjusted alt. belt; filled cab jack with fluid; repaired cracks in grill; checked oil leak on bottom of oil filler; straighten and repair bottom plate off left king pin	-	146.18
04/28/80	Oil change and service; tightened left-hand exhaust stack bolts; welded air breather bracket; repaired cab hydraulic leak; replaced air line to 5th wheel brake	-	78.28
05/21/80	Fixed fuel shut-off valve; checked for water leak in radiator; inspected RH steering tire - straightened panel and removed bracket and rewelded bracket and reinstalled; repaired battery box cover; checked air conditioner; checked cab jack; repaired air leak at brake valve	51.00	177.14
05/22/80	Replaced radiator and heater core hose; removed panels B1, B2, B3, and T1 for air circulation	-	674.60
06/10/80	Put jumper wire across a/c switch; repaired broken wire to temp. sending unit; replaced a/c compressor clutch assembly; evacuated system and charged with freon	-	159.71
06/15/80	Tire repair	-	10.82
06/17/80	Hooked up front rear end temp. wire; tightened groundwire on 4th front turn signal	-	57.50
06/22/80	Repaired air conditioner - outside service	-	23.48
07/02/80	Repaired fan clutch; repaired hose connector in volt meter; replaced a/c belt, clutch, and fuse; charged		

Date	Description	Noise Control Cost (in dollars)	Total Cost (in dollars)
	a/c system; rebuilt valve on air bag on air ride R/H; checked cab jack and filled with fluid; checked breaker box lights	-	331.52
07/02/80	Checked for heating; washed radiator and checked pump	-	34.99
07/07/80	Checked clutch fan; checked for short in electrical system - none; checked a/c - replaced thermofuse; checked air tank - replaced bolt		
07/11/80	Replaced steering tires	291.26	582.52
07/16/80	Installed thermostat; wash; replaced sensor on fan clutch	-	97.57
07/16/80	Checked clutch fan; replace thermofuse in a/c	-	71.08
07/29/80	Replaced a/c compressor; replaced a/c belt; vacuum and recharge a/c; replaced dryer in system; vacuum and recharged system again; installed windshield	-	412.09
09/19/80	Straightened and replaced oil filter access door; pulled R-1 panel; welded and replaced; lower channel; put rivets in trans. cover; replaced throttle cable and cap overflow tank and a/c; made and installed angle on Bl panel	102.00	226.91
09/24/80	Adjusted clutch		25.50
09/25/80	Service; checked clutch; tightened R/R tandem alignment	-	68.00
10/01/80	Installed new battery	-	119.95
10/06/80	Checked hydraulic assembly on clutch and replaced master cylinder; checked rear air bags	-	212.62

Date	Description	Noise Control Cost (in dollars)	Total Cost (in dollars)
10/13/80	Oil change and service; checked fan clutch	-	167.30
10/22/80	Replaced air cleaners; replaced oil kill switch; checked brakes	-	107.76
11/03/80	Service; installed light switch; installed cap on rad. surge tank	-	107.03
11/15/80	Service; installed fog lights; installed 25 amp breaker for fog lights; installed 2 prong switch for fog lights; replaced 1 low beam headlight; replaced both wiper blades	-	128.59
11/21/80	Changed oil and filters	-	107.66
11/28/80	Service; tightened small line fitting on power steering; checked brake linings	-	43.76
12/15/80	Service; had to bend R-1 panel to clear tire; fixed windshield wiper; installed service brake line; replaced fan hub and air scoop	4.59	285.81
12/26/80	Removed bottom plates on both ring pins and repaired; repaired short in fog light wire		76.00
01/09/81	Service; replaced power steering O ring; replaced 4 bolts in battery box; repaired waterhose; tighten alt. belt; replaced 1 fog light	-	145.04
01/30/81	Replaced battery; check starting problem; replaced fuel filter	-	395.04
01/30/81	Service call		42.50
	TOTAL		6694.30

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