N-96-01
II-A-203

EPA 550/9-82-331G

Field Test of a Quieted General Motors Brigadier Heavy-Duty Diesel Truck

Environmental Protection Agency

December 1981

Demonstration Truck Program 7

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

N-96-01
II-A-203

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 550/9-82-331G	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Field Test of a Quieted General Motors Brigadier Heavy-Duty Diesel Truck		5. REPORT DATE December 1981
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) E.K. Bender and J.A. Kane		8. PERFORMING ORGANIZATION REPORT NO. BBN Report No. 4796
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bolt Beranek and Newman Inc. 10 Moulton Street Cambridge, Massachusetts 02238		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-01-4998
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Noise Abatement and Control 401 M Street, SW Washington, DC 20460		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This report describes the field test and operational performance evaluation of a quieted General Motors Brigadier heavy-duty diesel truck. The noise of the truck had been reduced from 81.7 dBA to 71.6 dBA. The 12-month field test showed the noise control treatments to be effective and durable, although the noise level of the truck did increase slightly. The treatments did not have an adverse impact on vehicle operation and there was no evidence of payload displacement. The vehicle's fuel economy was better than that of comparison vehicles, but this was not caused by the noise treatments. Incremental maintenance time of 2.25 hours was attributable to treatment removal and interference while performing regular maintenance during the 12-month period.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Trucks, truck tractors, diesel engines, noise reduction, engine noise, exhaust systems, cost engineering, cost analysis, cost estimates	Truck noise control	13F 20A 14A

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
	20. SECURITY CLASS (This page)	22. PRICE

EPA Form 2220-1 (9-73)

Report No. 4796

FIELD TEST OF A QUIETED GMC BRIGADIER HEAVY-DUTY DIESEL TRUCK

Erich K. Bender
James A. Kane

December 1981

Prepared by:

Bolt Beranek and Newman Inc.
10 Moulton Street
Cambridge, Massachusetts 02238

Prepared for:

Environmental Protection Agency
Office of Noise Abatement and Control
401 M Street, SW
Washington, DC 20460

PREFACE

This report deals with the field testing by Bolt Beranek and Newman Inc. (BBN) of a quieted General Motors Brigadier 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 GMC Brigadier was one of two vehicles that completed an entire year of field testing.

Seven technical 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 technical 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 General Motors Corporation 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. ABF Freight System, Inc. operated the truck in its fleet and supplied much of the operational information provided in this report.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont.)

page

LIST OF TABLES

1. INTRODUCTION

This report describes the field test and operational performance evaluation of a quieted General Motors (GMC) Brigadier 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 yearlong field test are to determine the technical feasibility of the treatments and their impact on operating performance and cost.

The field test of the GMC Brigadier was conducted by ABF Freight System, Inc. (ABF), of Fort Smith, Arkansas. The test was directed by Bolt Beranek and Newman Inc. (BBN), EPA's contractor for the demonstration program. The vehicle logged 87,000 miles during the yearlong field test, from September 1980 to September 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, and showed no significant physical deterioration. The noise level of the truck did increase slightly over time.
- The treatments had no adverse impacts on the operation of the vehicle, and there was no evidence of payload displacement.
- The quieted unit had a fuel economy of 5.109 mpg in comparison to a fleet average of 4.939 mpg.
- The treatments had a minimal impact on maintenance. Approximately 2 1/4 hours of incremental labor time was attributable to the removal of treatments while maintenance tasks were performed over the one-year period.

Section 2 presents a summary description of the GMC Brigadier 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 GMC BRIGADIER

The GMC Brigadier had an original baseline noise level of 81.7 dBA. Its noise level was reduced to 71.6 dBA. This section describes the treatments employed to achieve this reduction. Readers who have already read the companion technology and cost report [2] 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 GMC Brigadier is shown in Fig. 1. The specifications of the vehicle are summarized in Table 1. The truck is equipped with a Detroit Diesel 6V92TT

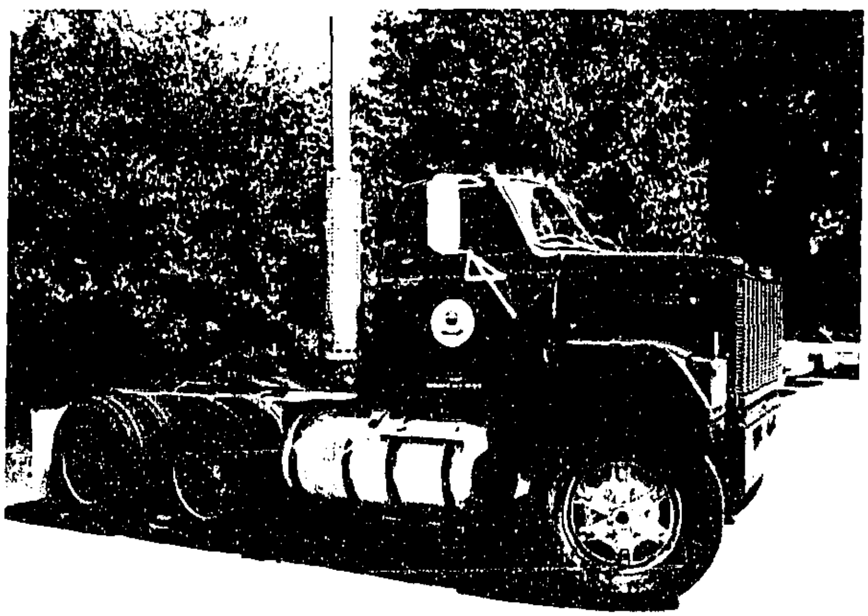


FIG. 1. BASELINE CONFIGURATION OF THE GMC BRIGADIER.

TABLE 1. SPECIFICATIONS SUMMARY OF THE GMC BRIGADIER.

Component	Specification
Vehicle Identification Number	T49CJ9V599235
Wheelbase	152 in.
Bumper to back of cab	92 3/4 in.
Gross Combination Weight Rating	80,000 lb
Engine	Detroit Diesel Allison 6V92TT (270 hp @ 1,950 rpm)
Transmission	Fuller RT-9509-A
Rear Axle	Eaton DS-340 (4.11 to 1)
Rear Suspension	Reyco 101-A
Fan Diameter	32 in.
Fan Clutch	GMC

V-6 engine rated at 270 hp at 1,950 rpm and a Fuller RT-9509-A transmission that has 9 forward speeds. Fully fueled and with a driver, the truck weighs 16,100 lb and has a gross combination weight rating (i.e., with loaded trailer) of 80,000 lb.

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 an underhood blanket of 1-in.-thick fiberglass coated with polyvinyl chloride to prevent flaking. Additional engine noise shielding on the baseline Brigadier included inner fenders and fender extensions in the front wheel areas.

Initial noise levels were measured by EPA at its Noise Enforcement Facility in Sandusky, Ohio, and by Bolt Beranek and Newman Inc. 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 Standard. The results, shown in Table 2, are fairly consistent between sites. We consider 81.7 dBA as the baseline noise level of the vehicle. 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 GMC BRIGADIER.

	Measured Level	
	EPA (dBA)	BBN (dBA)
Left side	80.6	81.5
Right side	80.9	81.7

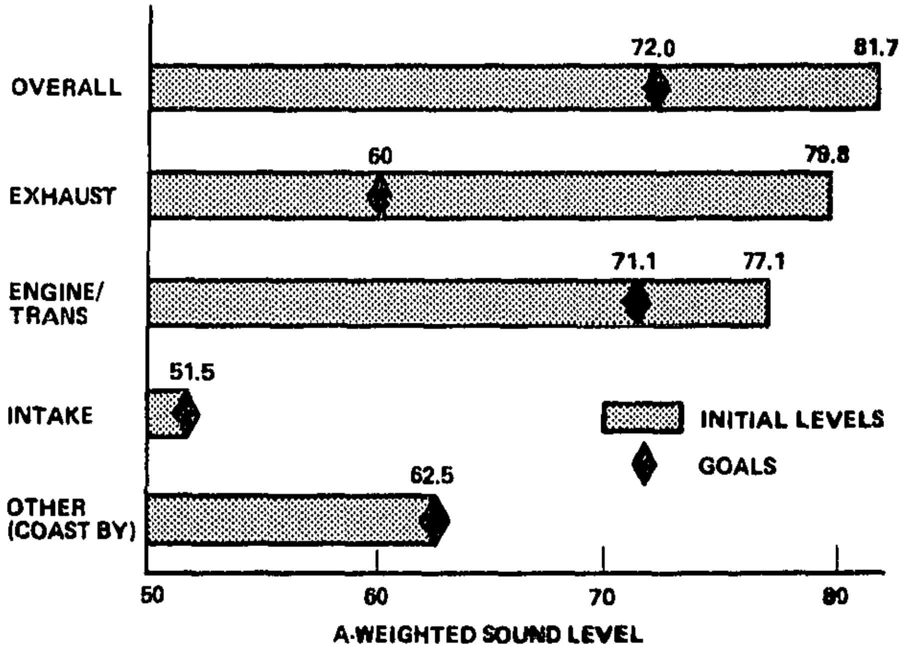


FIG. 2. OVERVIEW OF MAJOR NOISE SOURCE LEVELS AND GOALS.

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.

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, 10-in.-diameter mufflers, and 4-in.-stack silencers. A 5-in.-diameter

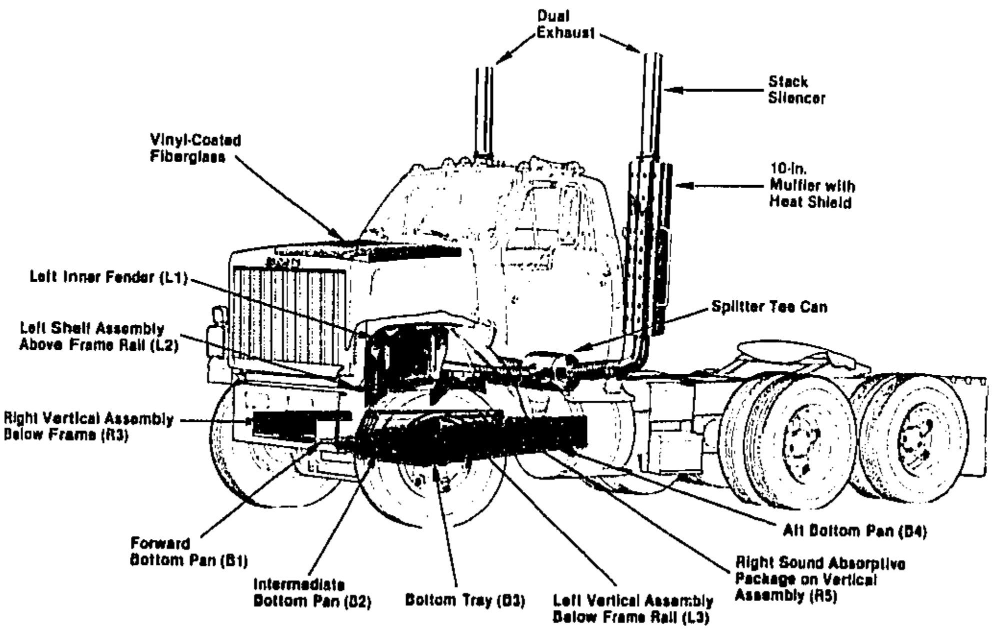


FIG. 3. NOISE CONTROL TREATMENTS INSTALLED ON GMC BRIGADIER.

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.

The bellypan for the Brigadier has two vertical panels that extend downward from the frame rails, three easily removable horizontal panels, and one small horizontal panel that is fastened with bolts. Figure 4 shows the front portion of the bellypan with the front bottom panel in place. Figure 5 shows the rear of the bellypan with the rear bottom panel removed, revealing the transmission and sound-absorptive panels on each vertical member. A sheet of 2-in.-thick aluminized polyester-faced foam was placed on the underside of the cab above the transmission.

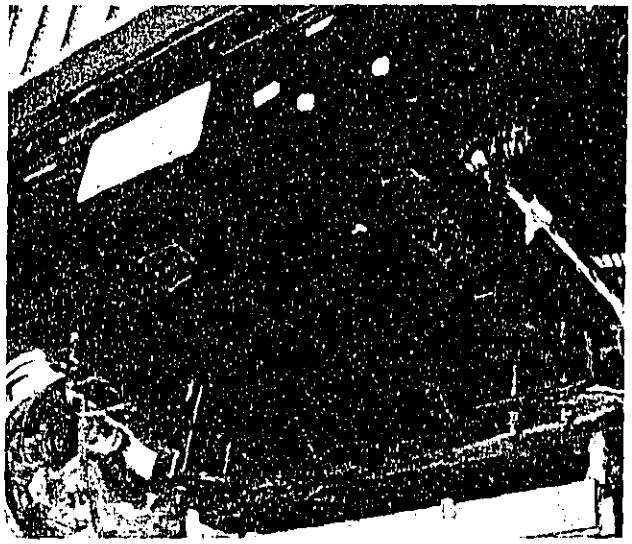


FIG. 4. THE BELLYPAN AS SEEN FROM UNDERNEATH THE FRONT OF THE BRIGADIER, LOOKING AFT.

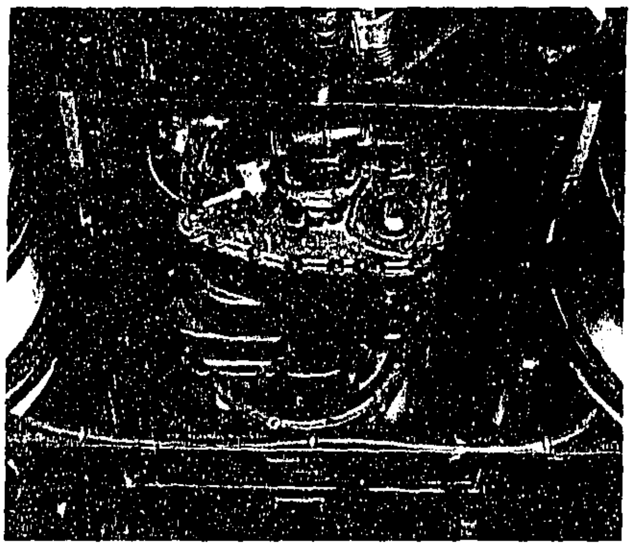


FIG. 5. REAR OF THE BRIGADIER BELLYPAN WITH BOTTOM PANEL REMOVED.

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

TABLE 3. DESCRIPTION OF ENCLOSURE NOISE TREATMENTS.

Identifier	Description
L1 and R1	Left and right PVC inserts in inner fender.
L2 and R2	Left and right side shelves for sealing 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 sealing the space 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.

3. FIELD TEST OPERATIONS

The field test was conducted from September 1980 to September 1981 by ABF Freight System Inc. (ABF), of Fort Smith, Arkansas. 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

The quieted Brigadier was operated by ABF Freight System, Inc., the motor carrier subsidiary of Arkansas Best Corporation. Arkansas Best has annual sales of $350 million and is listed on the New York Stock Exchange. While the corporation has several operating subsidiaries, its motor carrier subsidiary, ABF, is by far the most important and accounted for 79% of total corporate operating revenues in the last fiscal year.

ABF is a regular route commmon carrier. It operates coast-to-coast from 101 terminals and 10 regional service centers. The company has more than 6000 pieces of revenue equipment and routinely replaces a large portion of its truck tractor fleet each year. Each road tractor is normally replaced every three years, and the average ABF tractor is 1.75 years old.

ABF had been identified as a potential operator very early in the Demonstration Truck Program. The company had an excellent reputation and its management reporting systems would routinely provide most of the information required for the quieted Brigadier and comparison vehicles in the ABF fleet. The availability of a large comparison fleet of Brigadiers was a particularly strong reason for selecting ABF as an operator. The company was placing a fleet order for 194 Brigadiers. The original specifications of the quieted Bridgadier were matched to the ABF fleet purchase specifications. Thus, the quieted Brigadier could be compared to 194 vehicles with identical specifications.*

The quieted Brigadier, Unit 999 in the fleet, operated from ABF's Little Rock terminal. A typical ABF truck tractor operates throughout the ABF system in response to traffic requirements. The quieted Brigadier did not operate throughout the system, but instead was based in Little Rock and operated almost exclusively between Little Rock and Houston. This enabled ABF to monitor closely the vehicle's operation and performance. Information on the vehicle was forwarded from Little Rock to equipment and maintenance personnel at ABF's Fort Smith headquarters. The Little Rock-Houston route had high traffic volume and summer weather conditions on the route were a good test of the treatments' impact on cooling performance.

ABF developed and implemented procedures to monitor the quieted Brigadier's mileage, payload, fuel, and maintenance. These procedures supplemented the company's normal information reporting procedures. Original source documents (e.g., fuel records, shop tickets) were collected from the Little Rock and Houston terminals and compiled by the staff at Fort Smith into operations and maintenance information summaries. These information summary forms are shown in Figs. 6 and 7. An information summary form was prepared for each round trip, and each time the vehicle was serviced. These summaries were sent monthly to BBN, where they were reviewed, tabulated, and used to prepare many of the tables presented throughout this report.

Maximum reliance was placed on ABF's reporting procedures and systems. However, the maintenance reporting procedures were not designed to capture information on the noise treatments and

*The quieted Brigadier was actually included in the GMC production run for ABF's order.

OPERATIONS AND MAINTENANCE INFORMATION SUMMARY

Unit ABF 999

Period covered in this summary:

Dates: 11-18-80 to 11-19-80

Mileage: 26835 to 27710

Trip Segments

Date	Origin	Destination	Payload (lbs.)	GVCW
To	Little Rock, AR	Houston, TX	11,000	39,420
To	Houston, TX	Little Rock, AR	18,000	49,180
To				
To				
To				
		Average	14,500	44,300

Fuel Consumption 161 gallons

Fuel Economy 5.44 MPG

Maintenance - See Attached

Prepared by:

Betty Gilliam

Date December 10, 1980

FIG. 6. OPERATIONS INFORMATION SUMMARY.

EPA TRUCK MAINTENANCE INFORMATION SUMMARY

Unit ABF 999

Date of Service: 11 / 17 / 80

Shop Ticket: ______

Odometer Reading: 26836

	Regular Maintenance	Noise Control Maintenance [1]
In-House Labor (hours)	.75	
In-House Parts ($)		
Outside Repairs		

Attached Documents (check)

- [X] Shop Ticket
- [ ] Shop Ticket Addendum
- [ ] Outside Repair Bill

[1] Noise control maintenance includes repairs to the treatments and repairs to other truck parts caused by the treatments.

FIG. 7. MAINTENANCE INFORMATION SUMMARY.

particularly their impact on routine maintenance. A supplemental form, Shop Ticket Addendum, was designed and supplied to ABF 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.

ABF provided information on the 194 comparison Brigadiers in addition to the detailed information provided for Unit 999. The company supplied monthly summaries of mileage, fuel consumption, and maintenance costs for each of the 194 Brigadiers in the fleet and for the Brigadier fleet as a whole. The monthly summaries extended from March 1979, the first month Brigadiers entered the fleet, to June 1980. These monthly summaries, generated as part of ABF's management information system, provide the bulk of the comparative information presented in this report.

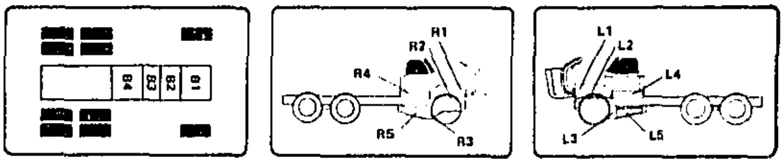
The quieted Brigadier did not enter service in March 1979, but rather in September 1980. Therefore, comparative information is presented on a "month of service" basis. March 1979 is Month 1 for the comparison fleet, while September 1980 is Month 1 for the quieted Brigadier. Comparisons are generally not for the entire 194 Brigadier fleet, but rather for 10 trucks that entered service in March 1979 and appear in the first monthly summary report supplied by ABF. These 10 trucks are referred to as the "comparison trucks"; the entire 194 unit fleet is referred to as the "comparison fleet."

SHOP TICKET ADDENDUM

Treatment Identifiers – GMC Brigadier Date: ____/____/8___

VIEW OF TRUCK

BOTTOM RIGHT LEFT



DESCRIPTION OF COMPONENTS

B1: Forward Bottom Pan
B2: Intermediate Bottom Pan
B3: Bottom Tray
B4: Aft Bottom Pan

R1: Right Inner Fender
R2: Right Shell Assembly Above Frame Rail
R3: Right Vertical Assembly Below Frame Rail
R4: Right Side Aft Enclosure Under Cab
R5: Right Sound Absorptive Package on Vertical Assembly

L1: Left Inner Fender
L2: Left Shell Assembly Above Frame Rail
L3: Left Vertical Assembly Below Frame Rail
L4: Left Side Aft Enclosure Under Cab
L5: Left Sound Absorptive Package on Vertical Assembly

Panels That Had To Be Removed*	SERVICE PERFORMED

Panels That Restricted Access But Were Not Removed*	SERVICE PERFORMED

* USE PANEL IDENTIFIERS LISTED UNDER DESCRIPTION OF COMPONENTS e.g. B1

COMMENTS ____

Attach this addendum to the shop ticket every time the demonstration truck is serviced

FIG. 8. SHOP TICKET ADDENDUM.

3.2 Chronology of Field Test Operations

The formal field test began on September 18, 1980 and continued through September 19, 1981. Major events during the field test are summarized below, along with the date and odometer reading for each event.

09/18/80 3045	Vehicle enters service with first trip on Little Rock-Houston route
10/12/80 10,918	Road service to seal exhaust leak in flex pipe between Splitter Tee Can and muffler. Pipe replaced upon return to Little Rock.
11/10/80 28,233	Second case of flex pipe replacement - this time between turbo and exhaust pipe.
12/31/80 42,161	39,116 miles in 3 1/2 months of service. Utiliza tion above fleet average.
01/22/81 45,667	Left Little Rock for EPA contractor's conference and MVMA tests.
02/02/81	Inspection by BBN reveals need to modify some treatments. Decision made to return vehicle to Cambridge for modifications by BBN before returning vehicle to service.
03/16/81	Vehicle arrives at Cambridge for modifications to enclosure and exhaust system.
04/27/81 49,599	Vehicle returns to operation on Little Rock-Houston route.
05/16/81 57,510	Vehicle involved in accident at Little Rock terminal. Damage to front of truck, but no damage to noise treatments.
06/12/81 57,510	Vehicle returns to service after repairs to front end completed.
06/26/81 61,889	Installed insulation panel on inside rear of cab in response to drivers' comments that rear of cab was getting hot.
09/19/81 93,145	Vehicle completes field test.

09/29/81 Vehicle arrives at BBN, Cambridge, for post-service
93,810 evaluation.

3.3 Mileage and Payload

The Brigadier accumulated 86,865 miles of fleet service during the field test at ABF.* The monthly and cumulative mileage is presented in Table 4. The monthly entries show the disruption in regular operation that occurred from January to June. The vehicle was effectively out of service for over three months, from mid-January to late April. It was involved in a minor accident in mid-May that kept it in the repair shop until mid-June. It returned to service in mid-June and continued in regular operation until September 19, 1981, a year and a day after it first entered service.

There were only five months when the vehicle was in regular operation for the entire month. Average mileage for these months was 11,512 miles per month. Average monthly mileage, exclusive of February and March, was 7897. As is evident from the monthly entries, the vehicle was in regular service during the hot summer months, providing a good test for the cooling performance of the vehicle.

The monthly operations of the vehicle are summarized in Table 5. The truck logged exactly 100 round trips, almost exclusively on the Little Rock-Houston route. Average trip mileage of 869 miles closely matches the 875-mile Little Rock-Houston round trip. The truck typically made three round trips each week. Average payload was 35,160 lb and, as is evident from the payload entries in Table 5, there was little month-to-month variation in

---

*Odometer mileage from September 18, 1980 to September 19, 1981 is 90,765; the 3900-mile difference is mileage accumulated during the January-April period while the truck was out of service.

TABLE 4. MONTHLY MILEAGE SUMMARY.

Month	Monthly Mileage	Cumulative Mileage
September	4,391	4,391
October	13,175	17,566
November	10,111	27,677
December	11,439	39,116
January	4,203	43,319
February	0	43,319
March	0	43,319
April	1,750	45,069
May	6,161	51,230
June	6,136	57,366
July	10,523	67,889
August	12,311	80,200
September	6,665	86,865

TABLE 5. MONTHLY OPERATIONS SUMMARY
GMC BRIGADIER.

Month	No. of Trips	Average Trip (mi.)	Average Payload	Average GVCW
September	5	878	31,300	59,805
October	15	878	33,333	61,070
November	13	778	33,308	53,292
December	13	880	35,346	56,135
January	5	841	34,600	59,192
February	0	-	-	-
March	0	-	-	-
April	2	875	42,500	70,965
May	7	880	36,428	62,879
June	7	877	37,500	59,791
July	12	877	36,632	58,340
August	14	879	34,783	57,684
September	7	952	37,857	54,957
Total	100	869	35,160	58,265

payload. Average gross vehicle combination weight (GVCW), i.e., truck tractor, trailer, and payload, was 58,265 lb. This is well below the 80,000 lb GVCW specification of the Brigadier. There was no evidence whatsoever that the additional weight of the noise control treatments ever displaced payload.

A comparison of the Brigadier and the comparison trucks is shown in Table 6 and Fig. 9. The data show two distinct trends. When the Brigadier was in regular service it typically accumulated more mileage than the average comparison truck. However, the data also show that the quieted Brigadier accumulated significantly lower mileage in its yearlong test than the comparison trucks. The average comparison vehicle logged 121,433 miles in 13 calendar months. The quieted Brigadier logged only 86,865 miles, 28% below the average comparison truck. The lower overall mileage is attributable to the truck being out of service during much of early 1981. The quieted Brigadier was above average during the first five months, as shown in Fig. 9. However, it fell behind during the next few months, while the comparison trucks kept averaging 8,000 to 11,000 miles per month.

TABLE 6. COMPARATIVE MILEAGE OF GMC BRIGADIER AND COMPARISON TRUCKS.

		Comparison Trucks Miles/Vehicle			
Month	Unit 999 Mileage	Average	Std. Deviation	Minimum	Maximum
1	4,391	2,400	1,171	400	3,859
2	13,175	6,253	1,243	4,469	8,117
3	10,111	8,791	2,072	4,611	12,100
4	11,439	11,058	2,917	7,023	15,206
5	4,023	10,237	3,540	1,701	14,056
6	-	8,443	1,948	5,015	10,909
7	-	11,972	3,332	5,819	16,357
8	1,760	9,399	1,662	7,280	13,003
9	6,160	8,707	2,370	4,445	12,666
10	6,136	11,730	2,981	6,474	14,985
11	10,523	9,652	1,915	6,949	12,799
12	12,311	9,494	1,652	6,719	11,769
13	6,665	13,269	1,621	11,299	15,433
Total Period	86,865	121,433	6,638	111,444	132,683

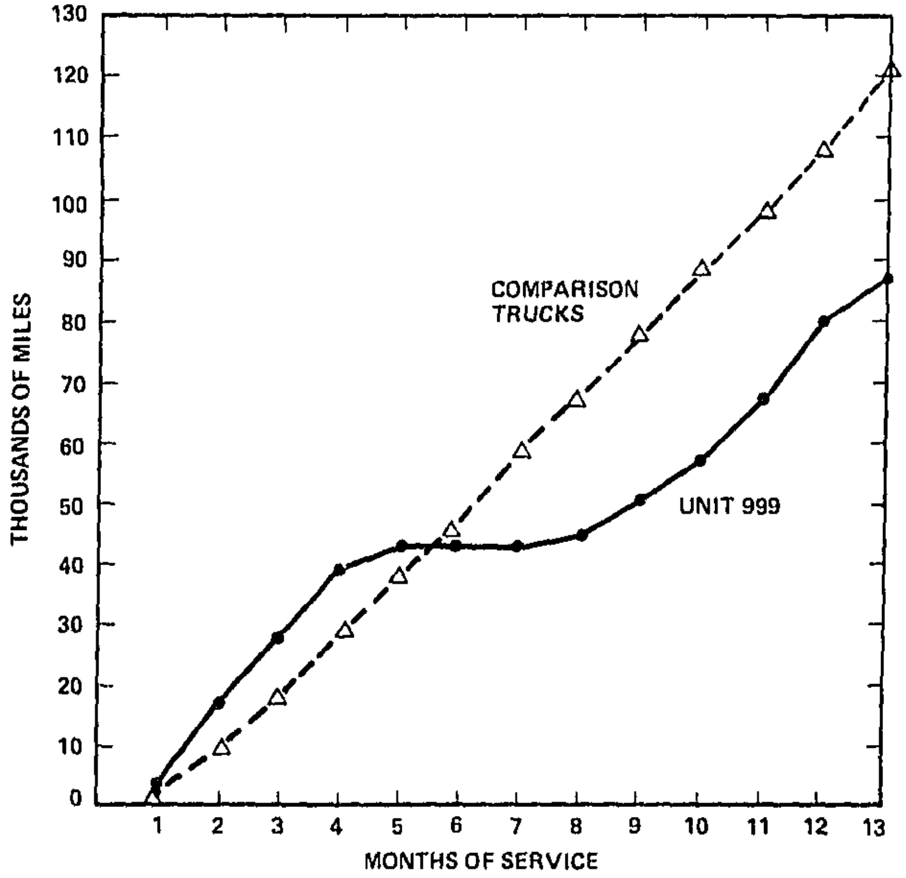


FIG. 9. COMPARATIVE MILEAGE.

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 and durability of treatments.

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 3.2 dBA over 17 months and approximately 87,000 miles. It is not clear whether the slight reduction in level during the first part of the test is statistically significant. Variations on the order of one dBA may be ascribed to variations among test sites and instrumentation. The 1.8-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. Moreover, the levels measured midway and at the end of the operational test are very consistent. The lack of appreciable change before and after noise treatments were repaired suggests that the major vehicle noise sources increased in level during the course of the fleet operation.

While the truck was at EPA's facility in July of 1980, EPA measured the noise level with various combinations of bellypan covers in place. The results, shown in Table 8, illustrate that removing the middle cover creates the greatest rise in noise level, and that all three covers are indeed needed to enable the vehicle to reach the 72-dBA goal.

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

Date	Vehicle Condition	Odometer Reading (approx.)	Location	40 CFR 205 Level (dBA)
July 3, 1980	Final configuration before leaving BBN	2,000	BBN - Cambridge	72.7
July 22, 1980	Arrived at GMC	N/A	GMC - Milford Proving Ground	71.6
July 29, 1980	Arrival at EPA	3,000	EPA - Sandusky	71.6
February 1981	Arrival at GMC	46,000	GMC - Milford Proving Ground	74.8
February 1981	GMC performed the following adjustments before testing: • Reposition exhaust tubing to break contact with exhaust masts • Cover fuel filter opening in right shelf	46,000	GMC - Milford Proving Ground	74.3
April 7, 1981	Before leaving BBN after repairs discussed in Sec. 4.2	47,000	BBN - Cambridge	74.7
December 3, 1981	Arrival at BBN	94,000	BBN - Cambridge	74.5

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	71.6
Off	On	On	72.8
Off	Off	On	73.2
On	Off	On	73.0
On	Off	Off	73.0
On	On	Off	72.4
Off	On	Off	73.2
Off	Off	Off	73.8

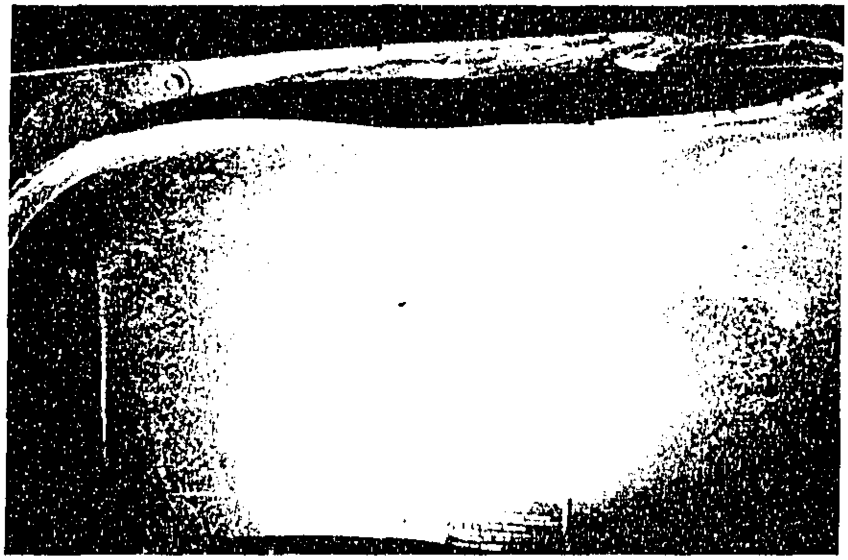
4.2 Mid-Test Treatment Modifications

When the truck was tested in February of 1981 (as discussed in Sec. 4.1), it was also inspected to determine possible reasons for noise level degradation and for treatment deterioration in general. Problems with the treatment were corrected before the truck was placed back in operational service.

Part of the noise level degradation may be attributable to gaps that developed between the inner fenders and the corresponding portions of the hood. Figure 10 shows a small gap on the right side and a larger gap on the left side of the vehicle. Evidently, the sheet-molded compound is heat-sensitive and sags when sufficiently warm.

Conversations with the vehicle manufacturer's technical staff indicate that inner fender sagging has been detected on other vehicles as well, and that solutions involving possible material or structural changes are under development. Since this project could not wait for these developments to be completed, we

(a) Right side



(b) Left side

FIG. 10. GAPS THAT DEVELOPED BETWEEN INNER FENDERS AND HOOD ON BOTH SIDES OF VEHICLE.

reinforced each fender with two metal strips, as shown in Fig. 11. These strips held the fender firmly against the hood.

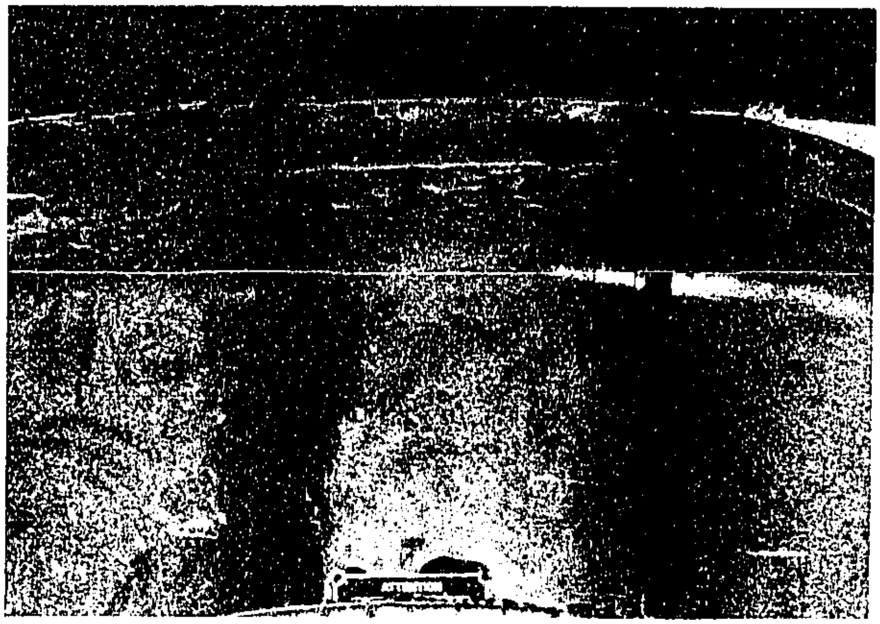


FIG. 11. STIFFENERS APPLIED TO RIGHT INNER FENDER.

When the enclosure was first installed, an opening was left in the right shelf (see R2 in Fig. 3) to accommodate the stock oil filter. ABF routinely replaces these filters with Luber Finer filters and locates them at the rear of the cab. Figure 12 shows the circular hole left in the shelf when the filter was removed. A significant amount of sound could propagate through this hole. The figure also shows that hose passing through an opening adjacent to the filter hole is being chafed by the shelf.

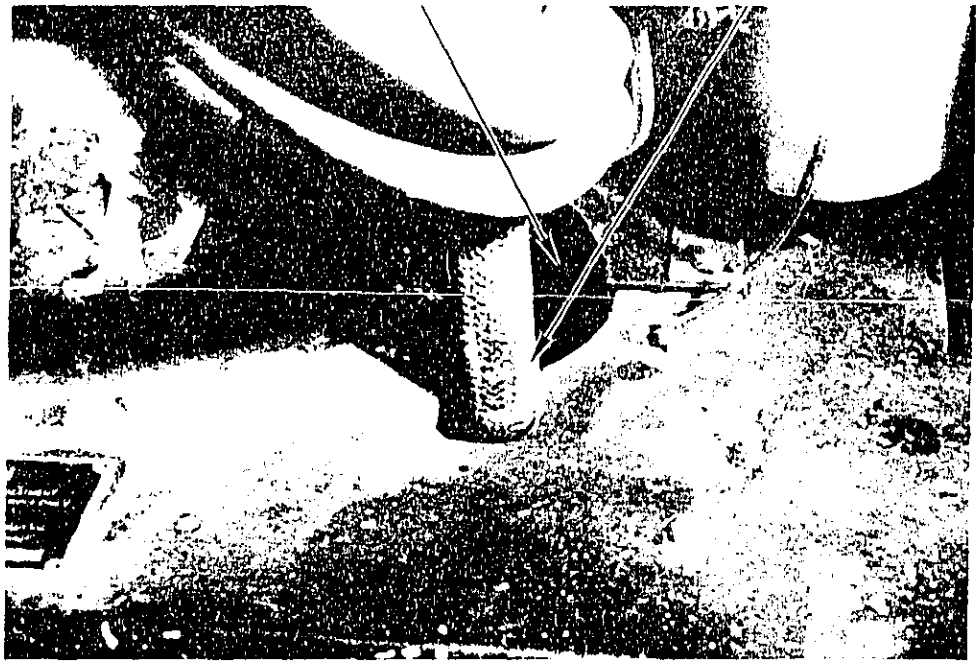


FIG. 12. RIGHT SIDE SHELF ILLUSTRATING OPENING FOR OIL FILTER AND CHAFING HOSE.

These problems were fixed by covering the oil filter hole with a neoprene sheet riveted to the shelf and supporting the hose with a clamp to prevent further chafing.

Further inspection of the right shelf discussed above revealed that it was bent from its original plane shape. Fig. 13 shows a side view of the shelf, below which is held a steel scale to illustrate the shelf deformation. The shelf is deformed by approximately 1/2 in.

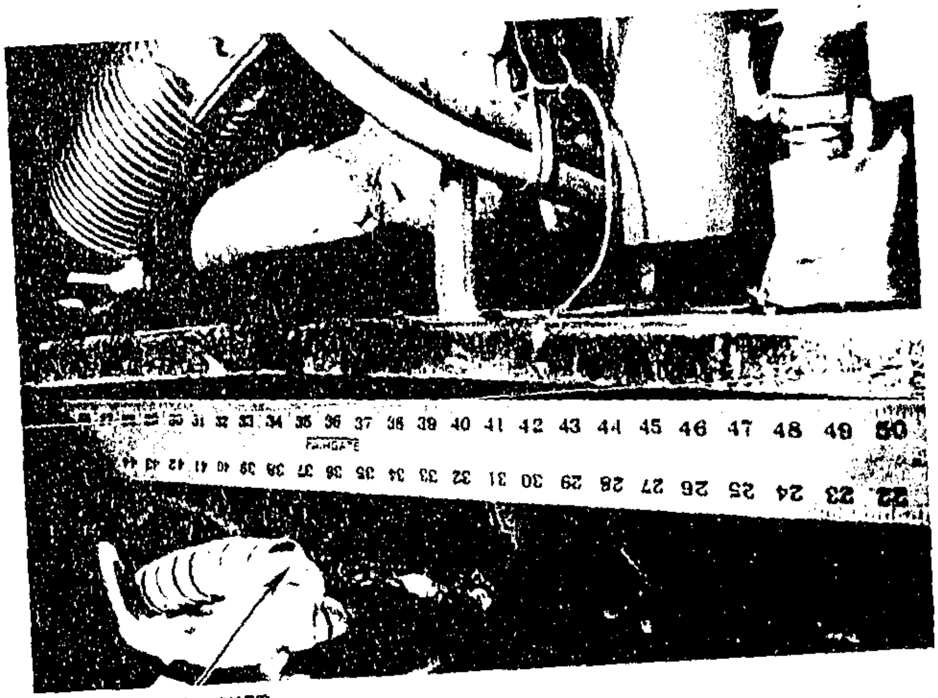


FIG. 13. BEND IN RIGHT SIDE SHELF (R2).

The cause of the shelf deformation was traced to the air hose bracket shown near the bottom of Fig. 13. For a range of steering angles, the top of the bracket is aligned directly under the lip of the shelf. If the truck traverses a large bump, the bracket could hit the shelf and deform it to the shape illustrated in the figure.

To prevent future contact between the shelf and bracket, the shelf was rebuilt as shown in Fig. 14. The contour was selected to match the contour of the original inner fender.

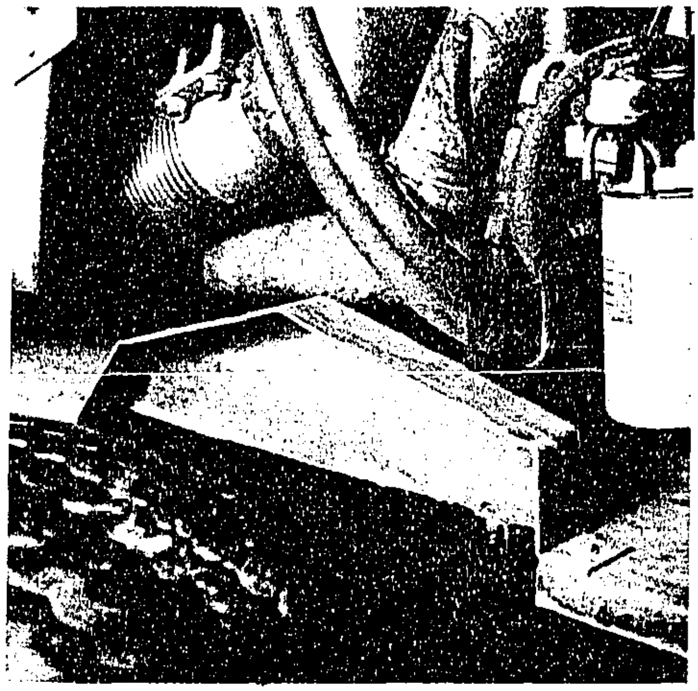


FIG. 14. REBUILT SHELF.

A minor clearance problem was detected between the front axle assembly and the right side of the bellypan (component R3 of Fig. 3). Figure 15a shows the gouge in the aluminum caused by the casting holding the rubber snubber and shock absorber. This casting is fastened to the front spring, which moves a lot as the vehicle chassis moves. Figure 15b shows that this problem did not occur on the left side of the vehicle. The problem was judged sufficiently minor that no corrective action was taken.

Quick-release fasteners that held the bellypan panels in place proved to be a chronic problem throughout the program. On the Brigadier, quarter-turn wing fasteners were used to hold the

(a) Right side

(b) Left side

FIG. 15. RELATION OF SNUBBERS TO RIGHT AND LEFT SIDE PANELS OF BELLYPAN (R3 AND L3).

forward bottom panel (B1) in place (see Fig. 21 of Ref. 2). These fasteners had apparently been found unsatisfactory by an ABF mechanic and were replaced with sheet metal lag bolts. An additional bolt was placed through the lip of the panel. Both are illustrated in Fig. 16.

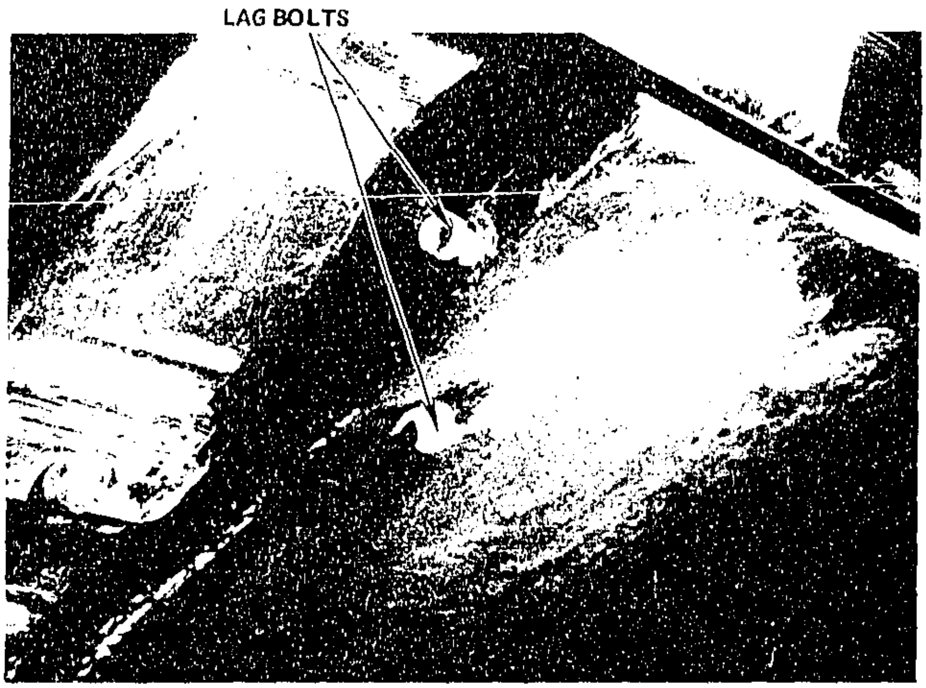


FIG. 16. LAG BOLTS USED TO HOLD PANEL B1 IN PLACE.

Before the truck was placed back in service, these bolts were removed and a heavier quarter-turn fastener was placed at the bottom corners of the bellypan. This fastener was larger and more rugged than those that had been used previously.

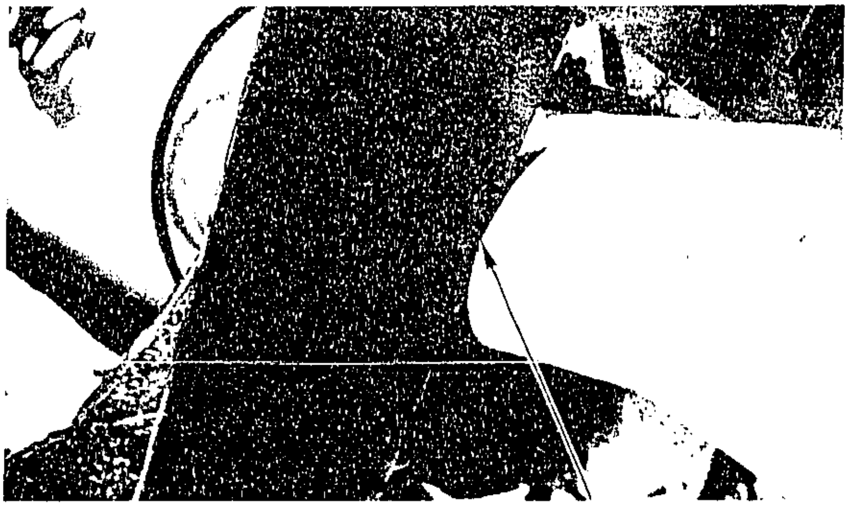
In its initially treated configuration, the truck contained a long unsupported section of exhaust line, extending from the turbocharger to the lower mast brackets. ABF found that several sections of a flex hose connecting the Tee-Can to the exhaust piping failed and had to be replaced. Somewhat longer replacement sections of hose were used, which caused the rear of the exhaust line to be shifted backwards. Figure 17 shows how the horizontal sections of exhaust line had pressed against the vertical masts. Rubbing between these components caused wear to both, but primarily to the mast.

The origin of the flex hose failure and subsequent misalignment and wear of tubing and masts clearly is associated with the initial lack of support of much of the exhaust tubing. Dynamic loads were apparently sufficient to lead to flex hose fatigue, and small clearances readily allowed for misalignments among components. The problem was addressed by welding a small bracket to the Tee-Can and fastening it to a cross frame member as illustrated in Fig. 18. This bracket provided support and a reference location to avoid possible future misalignments.

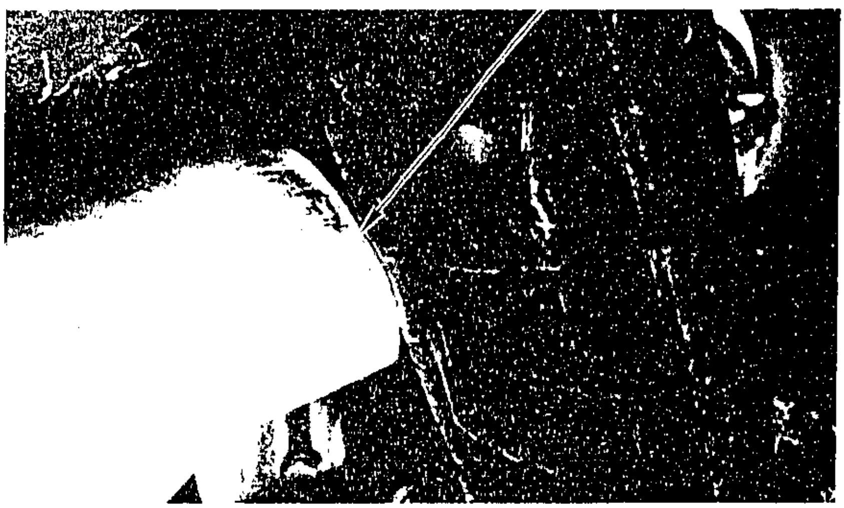
The truck manufacturer had installed rubber pads between the rear spring and spring bracket, probably to eliminate transient impact sounds. Figure 19 shows that the bolts and steel bar supporting the pad on the left side of the vehicle remained intact while the bolts on the right side failed. No corrective action was taken to repair this assembly.

4.3 Component Durability

At the end of the field test, the Brigadier was returned to BBN's Cambridge facility, where it was inspected to evaluate the durability of noise treatments. There was little deterioration after the repairs and modifications made midway through the program (discussed in Sec. 4.2).



(a) Right side



(b) left side

FIG. 17. CONTACT BETWEEN HORIZONTAL SECTIONS OF EXHAUST PIPE AND EXHAUST MAST.

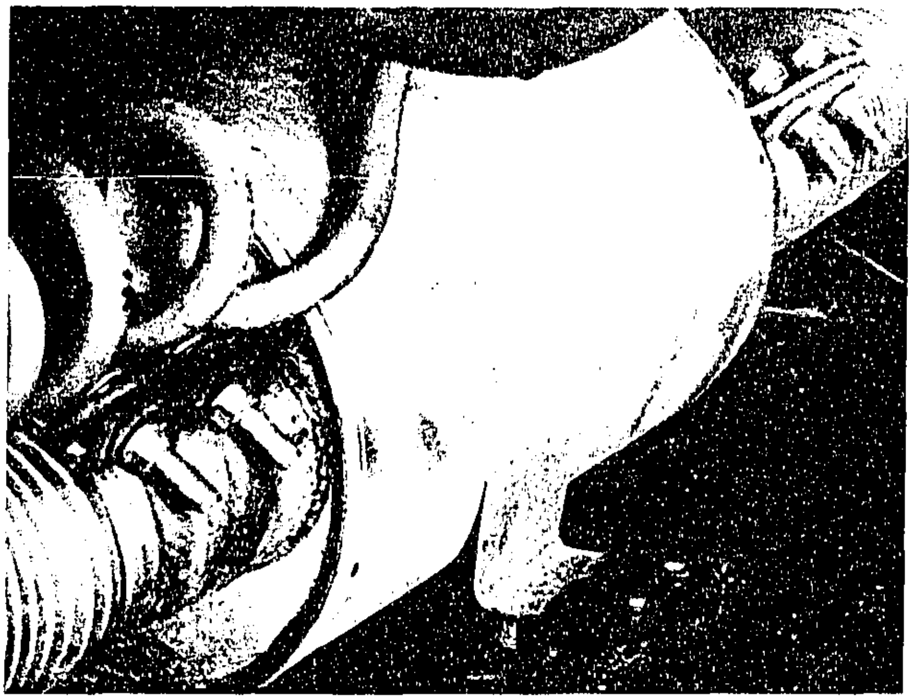
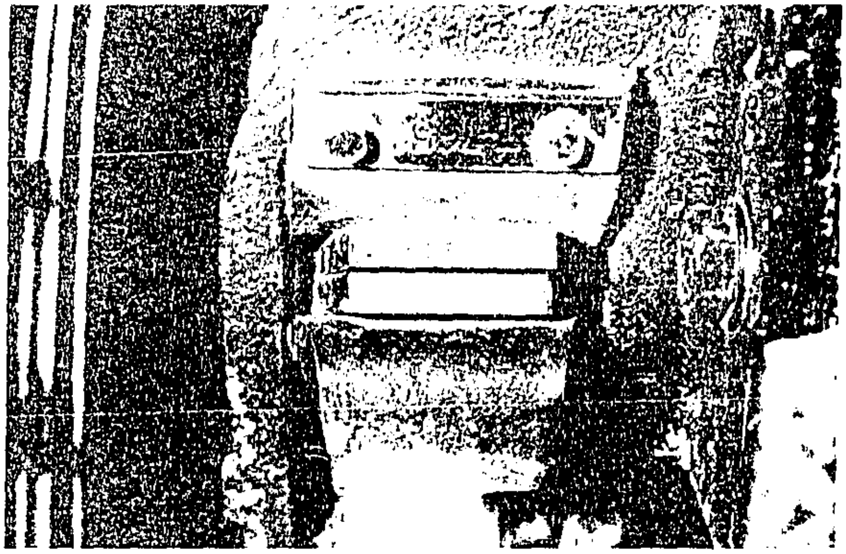
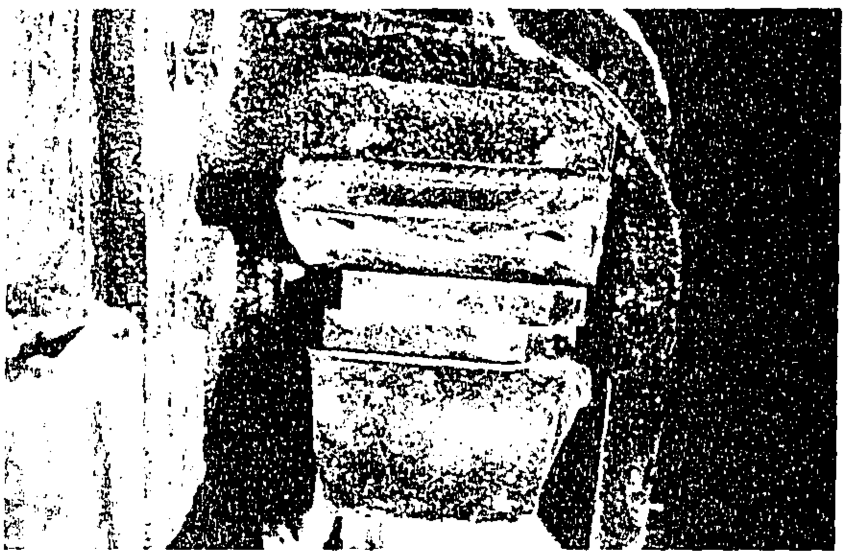


FIG. 18. BRACKET WELDED TO TEE CAN AND BOLTED TO FRAME CROSS MEMBER.



(a) LEFT



(b) RIGHT

FIG. 19. INTACT (LEFT) AND BROKEN (RIGHT) BOLTS USED TO HOLD RUBBER PAD TO SPRING BRACKET.

The exhaust system showed no signs of deterioration. The bracket welded to the Tee Can (see Fig. 18) retained its structural integrity and performed its function of supporting and keeping the exhaust line in place.

The reconfigured engine/transmission enclosure also proved durable for the most part during the last half of the operational test. Figure 20 shows that the seal between the inner fenders

FIG. 20. SEAL BETWEEN RIGHT INNER FENDER AND HOOD.

and hood remained tight. The reconstructed right side shelf (illustrated earlier in Fig. 14) showed no signs of wear. For the bellypan, the larger quarter-turn screw fasteners used to support the forward bottom pan, B1, retained their integrity, as shown in Fig. 21. However, the bail broke on one of the side latches used to support the intermediate bottom pan, B2, as shown in Fig. 22.

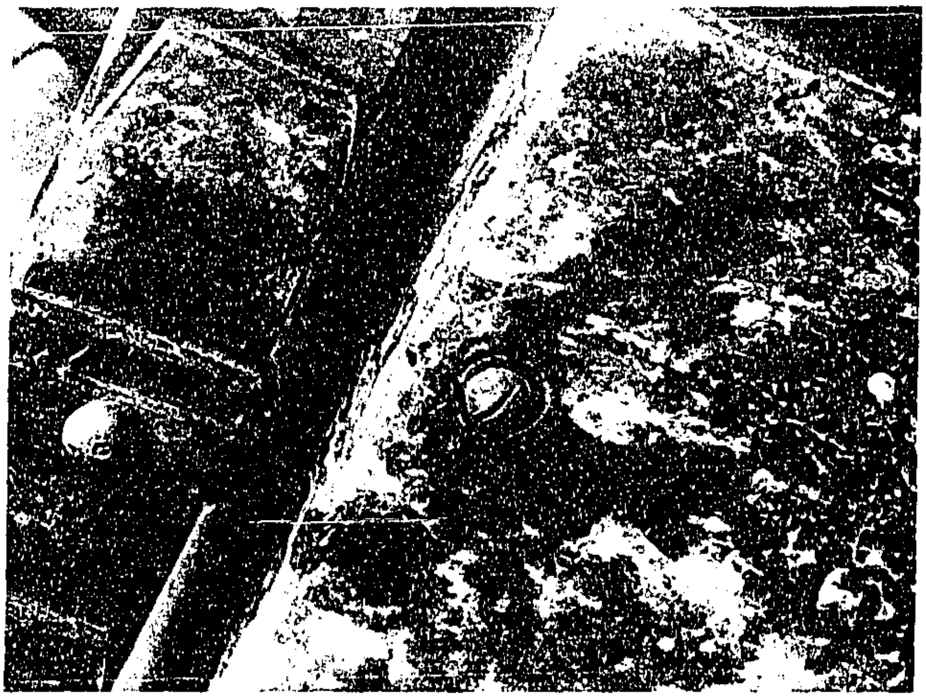


FIG. 21. QUARTER-TURN SCREW HEAD FASTENER USED TO HOLD FORWARD BOTTOM PAN (B1) IN PLACE.

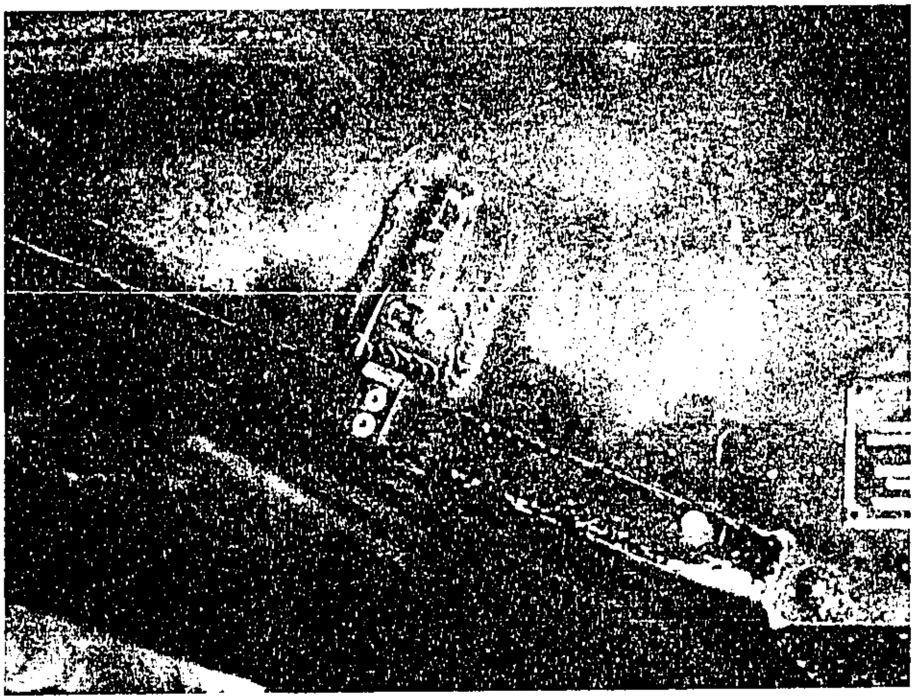


FIG. 22. BROKEN BAIL ON LATCH FASTENER USED TO SUPPORT INTERMEDIATE BOTTOM PAN (B2).

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 vehicle 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

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

where GPM is the incremental fuel consumption in gal/mile and GCW is the incremental gross weight.

The total weight increase associated with the noise treatment is 340 lb [1]. Using this value in the above equations gives an expected change in fuel consumption of 4.93×10^{-4} gal/mi. This represents 0.25% of the fuel consumption of 0.196 gal/mi determined from the field test.*

To estimate the effect of backpressure, consider the relationships between fuel efficiency and backpressure illustrated in Fig. 23. 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, for turbocharged diesel engines, 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. 23 and will be used for our estimates.

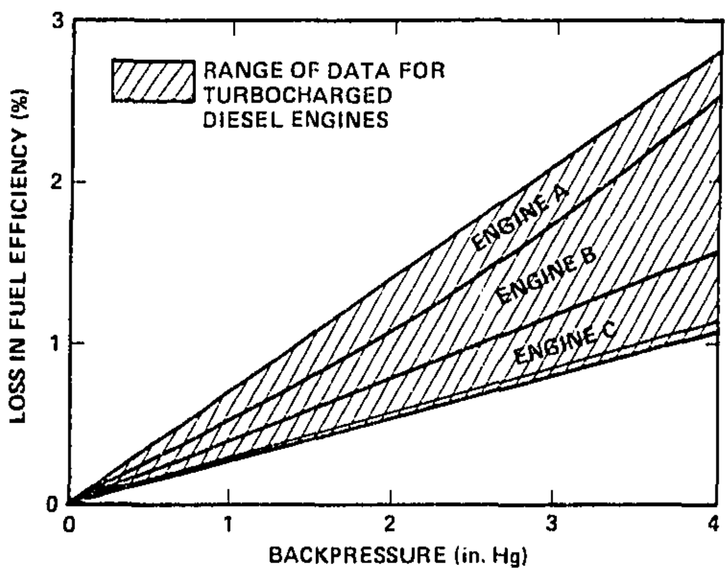


FIG. 23. RELATIONSHIP OF DIESEL ENGINE FUEL EFFICIENCY TO EXHAUST BACKPRESSURE.

---

*Based on 17,003 gal used in 86,865 miles of operation.

The backpressures generated by the original and final exhaust systems, measured under laboratory conditions on a Detroit Diesel 6V92TT engine, were 2.5 in. Hg and 2.1 in. Hg respectively. The reduction in fuel consumption owing to the lower backpressure of the final system is expected to be (2.5-2.1)(0.5) = 0.2%.

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:

	Estimated Increase <Decrease> in Fuel Consumption
Weight	0.25%
Backpressure	<0.20>
Net	0.05%

5.2 Field Data Analysis

The quieted Brigadier had a fuel economy of 5.109 miles per gallon (mpg) during the yearlong field test. This figure is based on 86,865 miles of service and 17,003 gallons of fuel. The monthly pattern of fuel economy for the quieted Brigadier is shown in Table 9 and as the solid line in Fig. 24. There was relatively little variation in fuel economy from month to month, both because of the regular route over which the vehicle operated and the small variation in payload. Monthly fuel economy ranged from a low of 4.834 mpg to a high of 5.240 mpg.

TABLE 9. COMPARATIVE FUEL ECONOMY FOR GMC BRIGADIER AND COMPARISON TRUCKS.

			Comparison Trucks Miles/Vehicle			
Month	Unit 999 Gallons	Miles/Gal	Average	Std. Deviation	Min.	Max.
1	851	5.160	*	*	*	*
2	2,576	5.115	5.774	0.914	3.885	7.419
3	1,952	5.181	4.293	0.647	3.114	5.107
4	2,249	5.086	5.549	0.984	3.385	7.016
5	836	5.082	4.946	1.281	1.813	6.622
6	-	-	5.082	1.886	3.811	10.318
7	-	-	5.741	0.375	5.091	6.245
8	362	4.834	4.313	0.453	3.440	4.906
9	1,218	5.058	4.474	0.475	3.390	4.970
10	1,202	5.105	4.715	0.541	3.939	5.601
11	2,058	5.113	4.770	0.518	4.162	5.845
12	2,427	5.073	4.390	0.601	3.443	5.377
13	1,272	5.240	5.613	0.564	4.728	6.812
Total Period	17,003	5.109	4.939	0.116	4.823	5.167

*Not reported because of anomalous data.

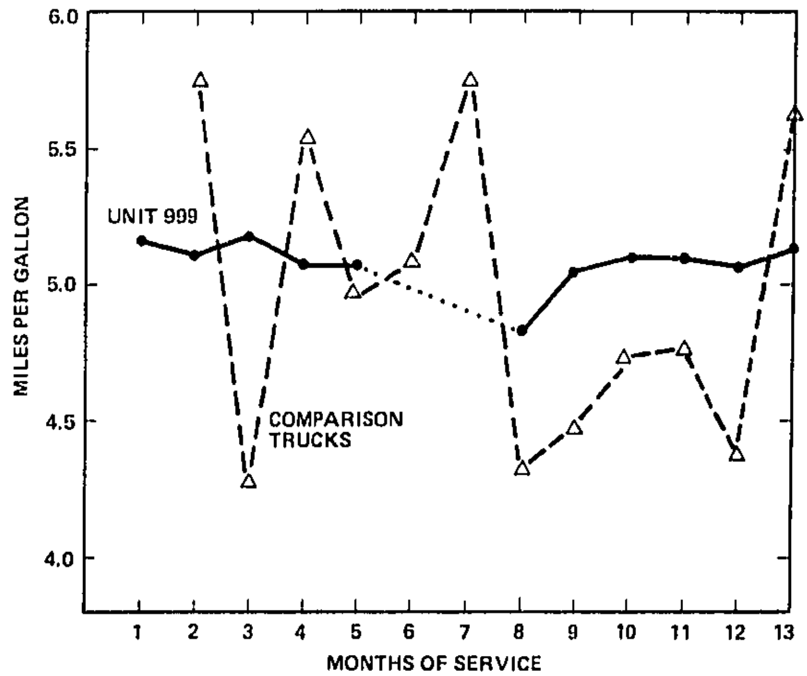


FIG. 24. COMPARATIVE FUEL ECONOMY.

Table 9 and Fig. 24 also present fuel economy data for the comparison trucks. These trucks had lower fuel economy - 4.939 mpg vs 5.109 for the quieted Brigadier. The month-to-month variation for the comparison trucks was also much greater than the Brigadier's. Fuel economy ranged from 4.313 to 5.741 mpg. This probably reflects variation in payloads, terrain, and weather condition, since the comparison trucks operated throughout the entire ABF system.

The comparison data presented in Table 9 are for the 10-truck comparison fleet. Since it was possible that these vehicles could have abnormal fuel economy, we also reviewed the fuel economy of ABF's overall fleet of 194 Brigadiers. The management reports supplied by ABF provided summary data for the Brigadier fleet for the 13-month period of March 1979 through March 1980. The Brigadier fleet logged 21,495,371 miles and consumed 4,359,280 gallons of fuel for fuel economy of 4.931 mpg. This is virtually the same as for the 10-truck comparison fleet.

In summary, the quieted Brigadier had slightly better fuel economy than the typical Brigadier in the ABF fleet. This result indicates that the noise control treatments did not have a significant adverse effect on fuel economy. The quieted Brigadier's above average fuel economy is probably related to the regularity of its payload and route.

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
- Deterioration 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 beneath the vehicle. To access major drive train service points (e.g., lubrication fittings), it is necessary to remove and replace panels. As illustrated in Figs. 25 and 26, this is done for panel B1 by releasing a pair of quarter turn fasteners and sliding the panel out of a groove at the rear. Figure 27 shows that panel B2 is removed by releasing side latches. Once the panel is removed, the engine oil drain plug (Fig. 28) is easily accessed.

With the hood tilted forward and the inner fenders removed, the engine and accessory components are easily reached. Figure 29 shows a mechanic removing the oil dipstick. The dipstick is readily accessible even with the fenders in place.

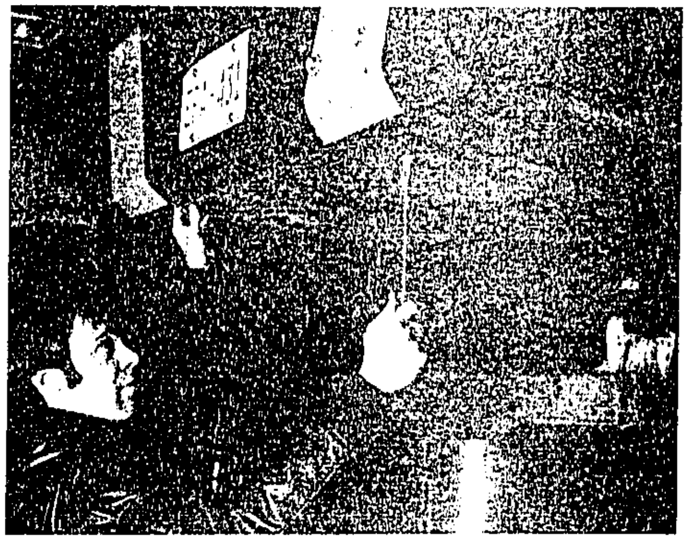


FIG. 25. RELEASING A QUARTER-TURN FASTENER.

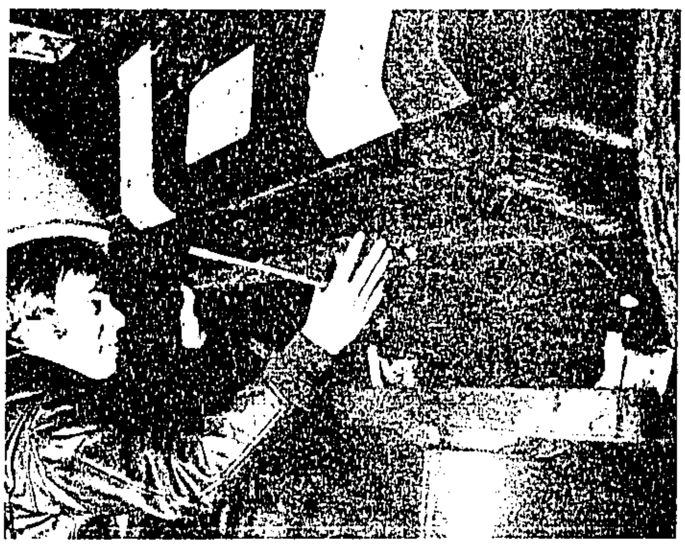


FIG. 26. REMOVING PANEL B1.

FIG. 27. RELEASING SIDE LATCH AND REMOVING PANEL B2.

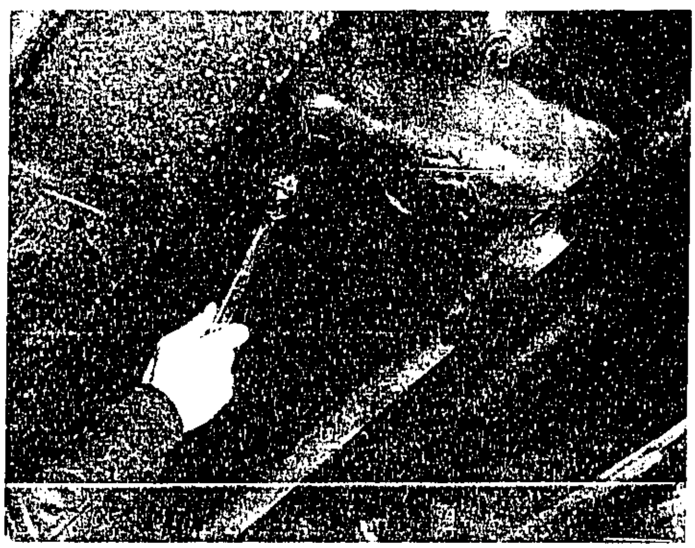


FIG. 28. ACCESSING OIL DRAIN PLUG ON ENGINE.

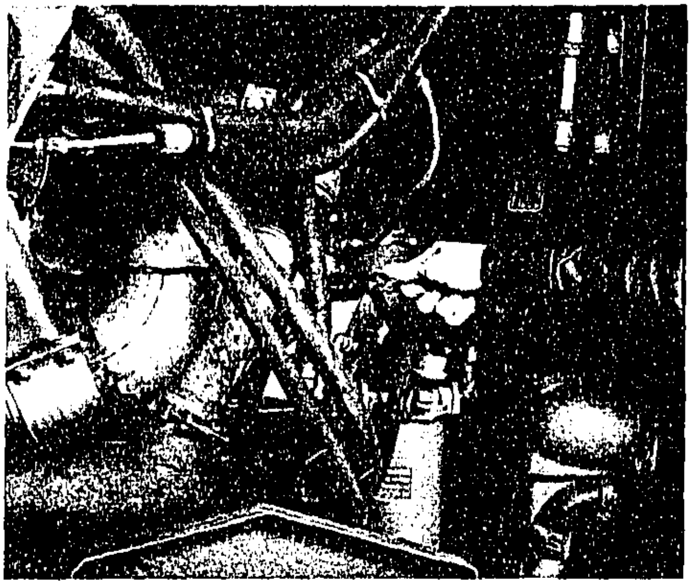


FIG. 29. ACCESS TO ENGINE AND ANCILLARY COMPONENTS.

6.2 Vehicle Maintenance Costs

The quieted Brigadier accumulated $3,511.26 of maintenance costs in its year of service. Slightly less than 6% of this total is attributable to the noise control treatments installed on the vehicle. This section describes the actual maintenance of the Brigadier during the field test. Major emphasis is placed on incremental maintenance costs attributable to the noise control treatments.

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 ABF at its Little Rock maintenance facility. The cost of regular maintenance was obtained directly from ABF shop tickets and maintenance information summaries (c.f. Fig. 7). 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 ABF's internal labor rate of $17.75 per hour. This rate included an overhead factor. Parts and materials were charged at ABF's actual costs. The costs of outside repairs were obtained from invoices to ABF for the repairs performed.

Maintenance costs attributable to the noise control treatments include:

- Costs of repairs to the treatments
- Costs of other repairs 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 10 presents an overall summary of maintenance costs for the quieted Brigadier. Regular maintenance service was by far the largest cost category, accounting for 90% of total costs. Outside repair costs were minimal, reflecting ABF's policy of performing as much work as possible in its own shops. Total treatment-related costs were $195.27. Repairs related to the noise treatments were $155.32, while incremental panel removal and reinstallation costs were estimated at $39.95.

TABLE 10. CUMULATIVE MAINTENANCE COSTS.

Type of Service		Cost (in dollars)
Regular		3168.27
Outside		147.72
Noise Related		195.27
• repairs	155.32	
• panel removal	39.95	
Total		3511.26

Table 11 presents the monthly pattern of maintenance costs for the quieted Brigadier. Maintenance costs were typically several hundred dollars per month. The most noticeable exception was December, when over $500 was spent to replace four batteries and the alternator. There was no particular pattern of repairs or chronic problem associated with Unit 999's maintenance. Rather, the year's maintenance could be characterized as consisting primarily of regular preventive maintenance and miscellaneous repairs and adjustments. The major exception is the costs associated with the accident in May.

The entries in Tables 10 and 11 exclude $1,545.52 for repairs to the vehicle as the result of the May accident. The accident occurred when a driver, ready to leave the Little Rock terminal, got out of the truck and apparently did not securely engage the parking brake. The Brigadier rolled forward and struck another truck. There was extensive damage to the front of Unit 999, but there was no damage to the engine enclosure. These accident-related repair costs are excluded from the analysis of maintenance costs, because they would invalidate a comparison with other Brigadiers in the ABF fleet and are clearly atypical costs.

TABLE 11. SUMMARY OF MAINTENANCE COSTS.

Type of Service				Maintenance Cost (in dollars)	
Month	Outside	Regular	Noise*	Month	Cumulative
September	42.50	220.29	4.44	267.23	267.23
October	65.79	362.87	39.93	468.09	735.32
November	0.0	167.40	26.63	194.03	929.35
December	0.0	749.54	8.88	758.42	1687.77
January	0.0	213.01	0.0	213.01	1900.78
February	-	-	-	-	-
March	-	-	-	-	-
April	0.0	84.35	8.88	93.23	1994.01
May†	0.0	75.44	4.44	79.88	2073.89
June	0.0	300.21	57.69	357.90	2431.79
July	39.43	382.10	35.50	457.03	2888.82
August	0.0	436.06	8.88	444.94	3333.76
September	0.0	177.50	0.0	177.50	3511.26
Total	147.72	3168.27	195.27	3511.26	3511.26

*Includes reported panel removal costs - see discussion in text.

†Excludes accident-related costs of $1,545.52.

Repairs related to noise treatment accounted for $155.32 of costs, or 4.4% of total costs. There were two items that accounted for the bulk of these charges:

- Replacement of exhaust system flex hose
- Installation of a heat insulation package at the rear of the cab.

There were other minor charges (e.g., $5-$10) for cleaning the panels once and repairing bottom panel latches on three occasions.

The original design of the exhaust system did not include a support for the Splitter Tee Can. Flex pipe connected the Splitter Tee Can to standard exhaust system piping. Portions of the flex pipe failed in October and November. The failure was attributed to vibration from the unsupported Tee Can. New flex pipe was installed by ABF and a Tee Can support subsequently was installed by BBN. There were no further problems with the exhaust system until July, when another portion of flex pipe between the turbocharger and the Tee Can had to be replaced. Approximately $84 was charged for these exhaust system repairs.

Drivers reported in late May and early June that the rear of the cab was getting warm. ABF's maintenance staff investigated the problem and surmised that heat from the Tee Can was radiating and warming the rear of the cab. ABF fabricated and installed an insulation package across the rear of the cab. The insulation package was charged at $53.25.

The discussion in Sec. 4 also addresses the problem with latches for the bottom of the engine enclosure. There were charges in April, May, and August to repair latches. In each instance the charge was for 15 minutes of labor.

Note that the costs of treatment-related repairs presented here exclude the costs of repairs made by BBN when the vehicle returned to BBN during the field test for the modifications described in Sec. 4.2.

The Brigadier was serviced by ABF 54 times during the field test; one or more panels were removed and reinstalled on 9 of the 54 occasions, i.e., 17% of the time. Information on the shop ticket addendum indicated that the bottom panels and the top side panels, R1 and L1, were typically the panels removed. On most occasions all the bottom panels were removed, although sometimes only one or two bottom panels were removed, depending upon the service to be performed. The bottom panels were removed for major maintenance activities such as "B" service, whereas the top side panels were typically removed for minor service under the hood.

The ABF mechanics reported on the shop tickets the time required to remove and reinstall the noise control panel. The shop ticket addendum indicated which panels had been removed. There was wide variation in the times reported by the ABF mechanics. For example, one mechanic reported that it took him a half hour to remove and reinstall panels B1, B2, B3, B4, R1, and L1, and another 15 minutes to fill out the form to record this fact. Another mechanic reported that he not only removed and reinstalled the bottom panels in a half hour but also steam cleaned them during that time. Still another mechanic reported that he removed and replaced the four bottom panels in 15 minutes.

BBN conducted time and motion studies to determine exactly how long it took to remove and install the four bottom panels and the two upper panels, R1 and L1. The studies were conducted at BBN and at a GMC maintenance facility in Boston. Table 12 presents the overall results of that analysis. The data show that it takes approximately 10 minutes to remove and reinstall these six panels. These data are for a mechanic working from a creeper under the truck.

Given these results, we concluded that some of the entries by the mechanics were obviously inflated. We reviewed the individual shop tickets and adjusted the reported times. We charged 15 minutes (or $4.44) for removing panels on each of the nine occasions when panels were removed. The resulting cost estimate, $39.95, probably overstates the actual cost, since not all six

TABLE 12. PANEL REMOVAL AND REINSTALLATION TIME.

Panels		BBN	GM-1	GM-2	GM Average	Overall Average
B1	R	0:35	0:19	0:20	0:20	0:25
	I	0:34	0:20	0:19	0:20	0:24
	Σ	1:09	0:39	0:39	0:39	0:49
B2	R	0:32	0:48	0:15	0:32	0:32
	I	1:20	1:26	0:55	1:11	1:14
	Σ	1:52	2:14	1:10	1:42	1:46
B3*	R	-	1:55	-	1:55	1:55
	I	-	1:50	-	1:50	1:50
	Σ	-	3:45	-	3:45	3:45
B4	R	0:42	1:00	0:27	0:44	0:43
	I	2:10	1:56	1:21	1:39	1:49
	Σ	2:52	2:56	1:48	2:22	2:32
R1	R	0:22	0:08	0:08*	0:08	0:13
	I	0:24	0:17	0:07	0:12	0:18
	Σ	0:41	0:25	0:15	0:20	0:21
L1	R	0:16	0:11	0:11	0:11	0:13
	I	0:44	0:30	0:24	0:27	0:33
	Σ	1:00	0:41	0:35	0:38	0:46
Total Bottom Panels	R				3:31	3:35
	I				5:00	5:17
	Σ				8:31	8:52
Total Side Panels	R				0:19	0:26
	I				0:39	0:51
	Σ				0:58	1:07

*B3 is a narrow structural member that acts as a stiffener. It is not designed for routine removal, although it is easy to remove.

removable panels were removed on each occasion. Nevertheless, we think it is proper to present what was reported by ABF (with BBN adjustments) rather than to report only estimates calculated from BBN's time and motion study.

To put these panel removal costs in perspective, 2 hours and 15 minutes of incremental time over 12 months represent 1.9% of the 118 labor hours charged to Unit 999 for regular service. The 2-hour and 15-minute estimate is less than what ABF mechanics reported, but more than what would be estimated using BBN's time and motion study.

ABF also supplied maintenance cost data for its Brigadier fleet. We analyzed these data for the 10 comparison trucks and developed a regression equation based on 16 months of data for each of the 10 trucks. The equation was estimated using ordinary least-squares techniques. The equation is:

$$Y = 140.36 + 0.026009X$$

where Y = cumulative maintenance cost
X = cumulative miles of service.

The coefficient of determination, R^2, is 0.882, indicating that 88% of variation in cumulative maintenance cost is "explained" by cumulative mileage. The slope coefficient is statistically significant and the standard deviation around the regression line is ±$446.

The regression line derived from this equation is shown as the solid line in Fig. 30. The actual maintenance costs for Unit 999 are shown as solid dots in Fig. 30. As is evident from the Figure, Unit 999's maintenance costs are above the trend line for the comparison trucks. The extent of the deviation is summarized

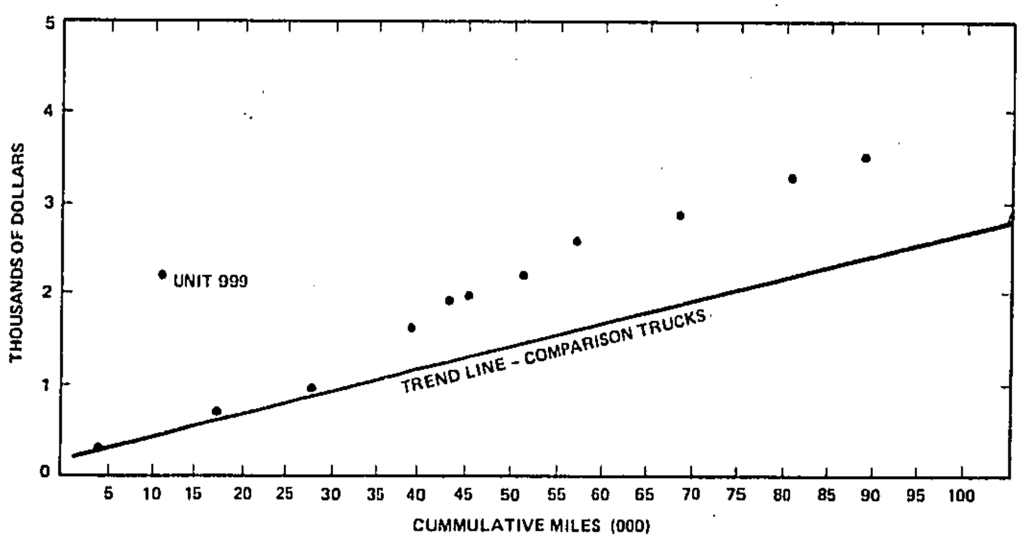


FIG. 30. COMPARATIVE MAINTENANCE COSTS.

in Table 13. Unit 999's maintenance costs are 46% above the fleet trend based on 86,865 miles of fleet service.

There is no obvious reason why the vehicle's maintenance costs were significantly higher than the fleet average. Even after excluding $195 of noise-related costs, the vehicle is still 38% above the fleet trend. ABF personnel also noted the above-average maintenance costs of the vehicle and could not identify any specific reasons for the above-average pattern. There is no indication that the costs are attributable to the treatments - review of maintenance records clearly verifies this. ABF representatives attribute some of the costs to the "extra attention" Unit 999 received as an experimental truck. In summary, the maintenance costs of Unit 999 were above average, but this was not caused by the noise control treatments on the truck.

TABLE 13. COMPARISON OF ACTUAL AND PREDICTED MAINTENANCE COSTS.

Maintenance Costs			
Mileage	Actual	Predicted	Deviation from Trend
4,391	267	255	+ 12
17,566	735	597	+ 137
27,677	929	860	+ 71
39,116	1687	1158	+ 528
43,319	1901	1267	+ 634
45,069	1994	1313	+ 681
51,230	2074	1473	+ 601
57,366	2432	1632	+ 800
67,889	2889	1906	+ 993
80,200	3334	2226	+1108
86,865	3511	2400	+1111

7. SUMMARY AND CONCLUSIONS

The major quantifiable results of this operational evaluation are shown in Table 14. 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 about a percent of overall maintenance costs for the vehicle. The impact on fuel consumption was an immeasurable 0.05%.

TABLE 14. SUMMARY OF QUANTIFIABLE TEST RESULTS.

	Change	
Parameter	**Value**	**Percent**
Noise Level	-10.1 dBA	-
Backpressure	- 0.4 in. Hg	16%
Weight	340 lb	2.4% of tractor 0.4% of GCWR
Noise-Related Maintenance Cost - normal[1]	$ 39.95	1.1%
abnormal[2]	155.32	4.4%
Fuel Consumption[3]	8.5 gal	0.05%

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

[2]Includes problems that could be corrected, such as exhaust pipe damage caused by inadequate clearance.

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

The issue of treatment durability extends beyond the measurable parameters presented in Table 14. 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 chronic failure of flex hose that occurred during the first part of the test was clearly alleviated when the Tee Can was supported from the chassis. Recurring damage to the right side shelf was avoided when the shelf was reconfigured to preclude contact with the air hose bracket.

Finding better ways to fasten covers requires some investigation. It may be that larger, more rugged side latches would suffice for the bottom panels. On the other hand, an alternate fastening arrangement such as that implemented on the IH vehicle may be necessary [8]. This problem can be solved through an experimental development effort.

It is clear that the noise treatment for this truck does not represent an ultimate solution, 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 with lower weight and cost might be feasible. We believe that, in the end, weight and costs could be reduced without compromising environmental noise levels.

REFERENCES

1. E.K. Bender, J.W. Ernest, and J.A. Kane, "Noise Reduction Technology and Costs for a Ford CLT 9000 Heavy-Duty Diesel Truck," Bolt Beranek and Newman Inc. Report No. 4379, October 1981.

2. E.K. Bender, J.A. Kane, and P.J. Remington, "Noise Reduction Technology and Costs for a General Motors Brigadier Heavy-Duty Diesel Truck," Bolt Beranek and Newman Inc. Report No. 4507, October 1981.

3. E.K. Bender, R.L. Bronsdon, J.A. Kane, and P.J. Remington, "Noise Reduction Technology and Costs for an International Harvester F-4370 Heavy-Duty Diesel Truck," Bolt Beranek and Newman Inc. Report No. 4667, October 1981.

4. E.K. Bender, J.A. Kane, and P.J. Remington, "Noise Reduction Technology and Costs for a Mack R686 Heavy-Duty Diesel Truck," Bolt Beranek and Newman Inc. Report No. 4795, December 1981.

5. "Noise Emission Standards for Transportation Equipment," 40 CFR 205, Federal Register, 41, No. 72, 13 April 1976.

6. G.E. Fax and M.C. Kaye, "The Economics of Quieting the Freightliner Cab-Over-Engine Diesel Truck," U.S. Department of Transportation Report No. DOT-TST-75-22, October 1974.

7. "A Common Sense Approach to Fuel Economy," Donaldson Co., Bulletin 1200-330, 1979.

8. E.K. Bender and J.A. Kane, "Field Test of a Quieted International Harvester F-4370 Heavy-Duty Diesel Truck," Bolt Beranek and Newman Inc. Report No. 4797, December 1981.

APPENDIX A:
SUMMARY OF VEHICLE MAINTENANCE

Date	Description	Noise Control Cost (in dollars)	Total Cost (in dollars)
09/21/80	Checked alternator; repaired accelerator; serviced w/s washer	-	26.63
09/22/80	Road service: repaired turn signal; fixed short on lights	-	42.50
09/24/80	Removed alternator: repaired and installed; removed T/rg. switch; repaired contact and installed; checked and adjusted clutch; checked rear differential; cleaned cab and windows; repaired dash light; noise control cost was panel removal B4, Rl, Ll	4.44	128.74
09/27/80	Sealed windshield; replaced low air beeper	-	47.17
09/29/80	Sealed brackets on top of cab; checked seat for air leaks; cleaned glasses	-	22.19
10/06/80	Replaced hub cap right front wheel; adjusted all mirrors; cleaned glass	-	44.38
10/08/80	Repaired left tail light; cleaned windows; ran and checked for oil leak; winterized unit; checked out seat for air leak and repaired rod on side of seat to seat belt	-	74.24
10/10/80	Repaired seat area leaking air; cleaned glass, filled washers; greased 5th wheel	-	22.19
10/12/80	Replaced flex exhaust pipe on right side; cleaned glass	17.75	92.42

Date	Description	Noise Control Cost (in dollars)	Total Cost (in dollars)
10/15/80	Removed panels B1,B2,B3,B4, R1,L1; took oil sample; filled out shop ticket addendum; replaced flex exhaust clamp; replaced differential seal; replaced wires to head and marker lights; repaired oil pan on bottom; checked oil leaks; cleaned windows	22.18	136.33
10/20/80	Repaired left hood cable; repaired tail light; cleaned glass	-	18.66
10/22/80	Repaired fuel leak; checked right front wheel seal for leak; cleaned glass	-	31.06
10/27/80	Checked and greased front end; repaired w/s washer; cleaned cab and glass	-	31.06
10/30/80	Checked for no power	-	17.75
11/10/80	Repaired exhaust leaks (flex pipe pipe was broken); checked steering; greased front end and spring shackles; cleaned glass	17.75	39.94
11/13/80	Brake inspection; repaired right hood cables; took oil sample; air tires; cleaned glass and cab	8.88	82.18
11/15/80	Checked over tractor; cleaned windows	-	17.75
11/17/80	Fixed water leak around windshield	-	13.31
11/25/80	Replaced hood cables; cleaned all glasses	-	27.54
11/26/80	Checked rear alignment; greased 5th wheel; repaired tail lights; serviced w/w	-	13.31

Date	Description	Noise Control Cost (in dollars)	Total Cost (in dollars)
12/04/80	Checked oil in transmission	-	17.75
12/08/80	Replaced hood cable springs; repaired tail lights; cleaned glass and cab	-	28.45
12/18/80	Took oil sample; steam cleaned bottom panels B1,B3,R1,L1; removed right rear wheel and steam cleaned bottom panels; cleaned brake shoes and replaced seal and rings; repaired cab light, horn; checked air leak and repaired	8.88	155.73
12/22/80	Replaced 4 batteries; replaced alternator; serviced w/s and cleaned glass	-	556.49
01/12/81	Cleaned windows		8.88
01/16/81	Removed safety equipment and air shield; steam cleaned complete unit and 5th wheel; painted frame and wheels; shined stacks and mufflers; cleaned glass and lights	-	177.50
01/21/81	Replaced air shield; replaced safety equipment	-	26.63
04/26/81	Repaired seat; adjusted headlights; cleaned windows	-	22.19
04/29/81	Changed engine oil and oil filter; oil sample; changed transmission oil and oil filter; repaired panel latch on B2 left side; cleaned glass	8.88	71.04
05/07/81	Checked tractor for ignition difficulties; tightened battery cables and checked batteries; cleaned windows; adjusted headlights	-	26.63

Date	Description	Noise Control Cost (in dollars)	Total Cost (in dollars)
05/09/81	Checked tandem alignment and front end; tightened dog house clips; checked a/c for freezing up; cleaned glasses; greased 5th wheel	-	35.50
05/17/81	Repaired left tail light; checked out for exhaust leak; closed cab vent over engine cover; cleaned windows and filled washer	4.44	17.75
06/14/81	Repaired dash light; adjusted w/s washers; installed permits; repaired a/c; cleaned cab and glasses	-	45.84
06/16/81	Checked out starter; replaced all ground wires to starter; checked out a/c unit; put in almost 1 lb of Freon; serviced washer; cleaned cab and glasses	-	53.25
06/19/81	Brake inspection; took oil sample; removed and replaced panels under engine; checked a/c; replaced dryer and evacuate system; charged and run to check; repaired right radiator brace; repositioned fan belts; freed right front spring; cleaned glass	4.44	178.04
06/26/81	Installed insulation panel on back of cab	53.25	53.25
06/27/81	Changed fuel filter; checked fuel pressure; checked air filter; cleaned windows	-	27.52
07/04/81	Adjusted headlight; cleaned glass	-	13.31
07/11/81	Checked tractor for pulling to the right; aligned rear axles to front axle; checked alternator and charging; cleaned windows	-	166.30

Date	Description	Noise Control Cost (in dollars)	Total Cost (in dollars)
07/13/81	Replaced oil line to turbo	-	39.43
07/16/81	Repaired exhaust leak; set toe in; cleaned cab and glass	31.06	53.25
07/22/81	Took oil sample; removed and replaced panels; finished brake linings; checked for pulling right; aligned tandem; checked for leaks	4.44	123.09
07/26/81	Checked for pulling to the right; rear tandem out of alignment; realigned and cleaned glass	-	35.50
07/29/81	Replaced battery; covers had to be straightened; cleaned cab and glass; greased 5th wheel	-	26.15
08/01/81	Miscellaneous service	-	100.65
08/06/81	Checked and replaced fuel filters; repaired lights; cleaned cab	-	26.63
08/13/81	Checked out a/c; replaced air conditioner valve and position valve; replaced dryer; charged unit; checked for a/c leaks; cleaned glasses	-	148.58
08/20/81	Brake inspection; took oil sample; removed and replaced panels; checked right front cap filter plug; checked for leak; removed left rear wheel and steam cleaned bearings and brake; cleaned axle; put seal, locknut, washer, and side nut; oiled brake; checked cover on left side panel latch	8.88	138.02
08/29/81	Repaired seat back; changed left parking light; cleaned windows and greased 5th wheel	-	17.75
08/31/81	Checked a/c unit; cleaned glasses	-	13.31

Date	Description	Noise Control Cost (in dollars)	Total Cost (in dollars)
09/01/81	Miscellaneous service	-	35.50
09/13/81	Steamed engine, frame and wheel; painted wheel and rim	-	71.00
09/16/81	Checked brakes; cleaned windows and cab	-	17.75
09/18/81	Miscellaneous service	-	53.25
	TOTAL	195.27	3511.26

7