N-96-01
II-A-204

EPA 550/9-82-331H

Field Test of a Quieted International Harvester F-4370 Heavy-Duty Diesel Truck

Environmental Protection Agency

December 1981

Demonstration Truck Program

8

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

U-96-01
II-A-204

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 550/9-82-331H	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Field Test of a Quieted International Harvester F-4370 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. 4797
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 International Harvester F-4370 heavy-duty diesel truck. The noise of the truck had been reduced from 81.1 dBA to 72.7 dBA. The truck accumulated 36,000 miles in 5 months of service. The treatments were effective and durable, and the noise level of the truck did not increase. The treatments did not have an adverse impact on vehicle operations and there was no evidence that the weight of the treatments displaced payload. The treatments did not have a measurable effect on fuel consumption. The treatments had a minimal impact on maintenance time.

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. 4797

FIELD TEST OF A QUIETED INTERNATIONAL HARVESTER F-4370 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 International Harvester F-4370 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 full year of fleet service. The International Harvester truck completed five months of field service before the end of the program in late 1981.

Seven final 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 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 International Harvester Company provided technical information on the truck. The Cummins Engine Company performed

TABLE OF CONTENTS

CORRECTION!

THE PREVIOUS DOCUMENT(S) MAY HAVE BEEN FILMED INCORRECTLY . . .

RESHOOT FOLLOWS!

cooling tests at its facility in Columbus, Indiana. 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 Coca-Cola Bottling Company of Northampton, Massachusetts 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 TABLES

1. INTRODUCTION

This report describes the field test and operational performance evaluation of a quieted International Harvester F-4370 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 field test are to determine the technical feasibility of the treatments and their impact on operating performance and cost.

The field test of the International Harvester F-4370 was conducted by the Coca-Cola Bottling Company of Northampton, Massachusetts. The test was directed by Bolt Beranek and Newman Inc. (BBN), EPA's contractor for the demonstration program. The vehicle logged 35,778 miles during the 5-month field test, from June 1981 to November 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 the noise level of the truck did not significantly increase over time.
- The treatments had no adverse impacts on the operation of the vehicle and there was no evidence of payload displacement.
- The weight of the treatments did not have a measurable effect on fuel consumption. The quieted unit had a fuel economy of 4.868 mpg, while a comparison untreated unit had an average fuel economy of 4.193 mpg.
- The treatments had a minimal impact on maintenance. Approximately 2 3/4 hours of incremental labor time was attributable to the removal or interference of treatments while maintenance tasks were performed over a five-month period.

Section 2 presents a summary description of the International Harvester F-4370 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 INTERNATIONAL HARVESTER F-4370

The International Harvester F-4370 (IH F-4370) had an original baseline noise level of 81.1 dBA. Its noise level was reduced to 72.7 dBA. This section describes the treatments employed to achieve this reduction. Readers who have already read the companion technology and cost report [3] 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 IH F-4370 is shown in Fig. 1. The specifications of the vehicle are summarized in Table 1. The truck is equipped with a Cummins NTC-350 BC in-line

FIG. 1. BASELINE CONFIGURATION OF THE INTERNATIONAL HARVESTER F-4370.

TABLE 1. SPECIFICATIONS SUMMARY.

Component	Specification
Vehicle Identification Number	D2137J6B27369
Wheelbase	162 in.
Bumper to back of cab	177 in.
Gross Combination Weight Rating	80,000 lb
Engine	Cummins NTC 350 BC (350 hp @ 2100 rpm)
Transmission	Fuller RTF 1110
Rear Axle	Eaton RA-355 (3.73 to 1)
Rear Suspension	Dayton 4-spring 50 in.
Fan Diameter	28 in.

diesel engine. It is an I-6 direct injection engine with a turbocharger, rated at 350 hp at 2100 rpm. The transmission is a Fuller (Division of Eaton Corp.) Model RTF-1110 and has ten forward speeds. The actual weight of the tractor after installation of components by BBN and the operator was 16,020 lb.

The baseline configuration did include initial noise treatments. The truck was equipped with a single 5-in.-diameter exhaust line containing a 9-in.-diameter unwrapped muffler with a standard 44 1/2-in. body length. The truck was equipped with a thermostatically controlled 28-in.-diameter cooling fan. Engine noise was partially controlled by rubber shields that fit in the wheel wells and sound-absorptive material applied to the firewall.

The truck was initially noise-tested by EPA at its Noise Enforcement Facility at Sandusky, Ohio, and subsequently by BBN at Hanscom Field in Bedford, Massachusetts. Both tests were performed in accordance with the test procedure prescribed by EPA in 40 CFR 205 [5]. Table 2 shows that the exterior noise levels measured at each location are within about 1 to 2 dBA of each other. 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. BASELINE OVERALL NOISE LEVELS.

	EPA Measurements (dBA)	BBN Measurements (dBA)
Left Side	79.2	81.1
Right Side	79.4	79.5

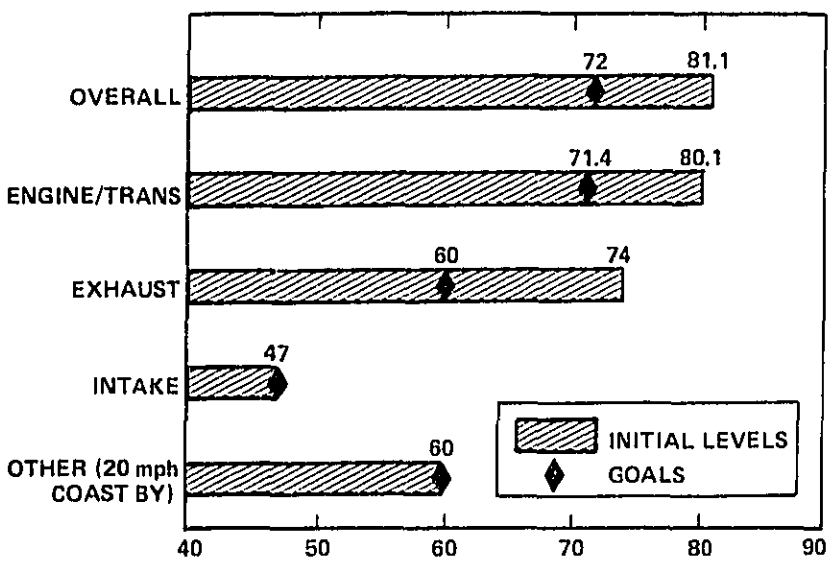


FIG. 2. OVERVIEW OF MAJOR NOISE SOURCE LEVELS AND GOALS.

2.2 Description of Noise Control Treatments

Three major treatments were used to reduce the noise of the International Harvester F-4370 truck. The treatments are:

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

Figure 3 is a graphic representation of the BBN treatments.

Exhaust System Modifications

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 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 bracket to accommodate the dual system.

Engine/Transmission Enclosure

A tunnel enclosure was designed to shield the community from engine and transmission noise. The enclosure is open at the front and rear of the truck to allow cooling air to flow through the radiator, over the engine and transmission, and out the rear. As illustrated in Fig. 3, the hood and the bottom of the cab form the top of the enclosure. The remaining major areas requiring treatment to complete the enclosure are:

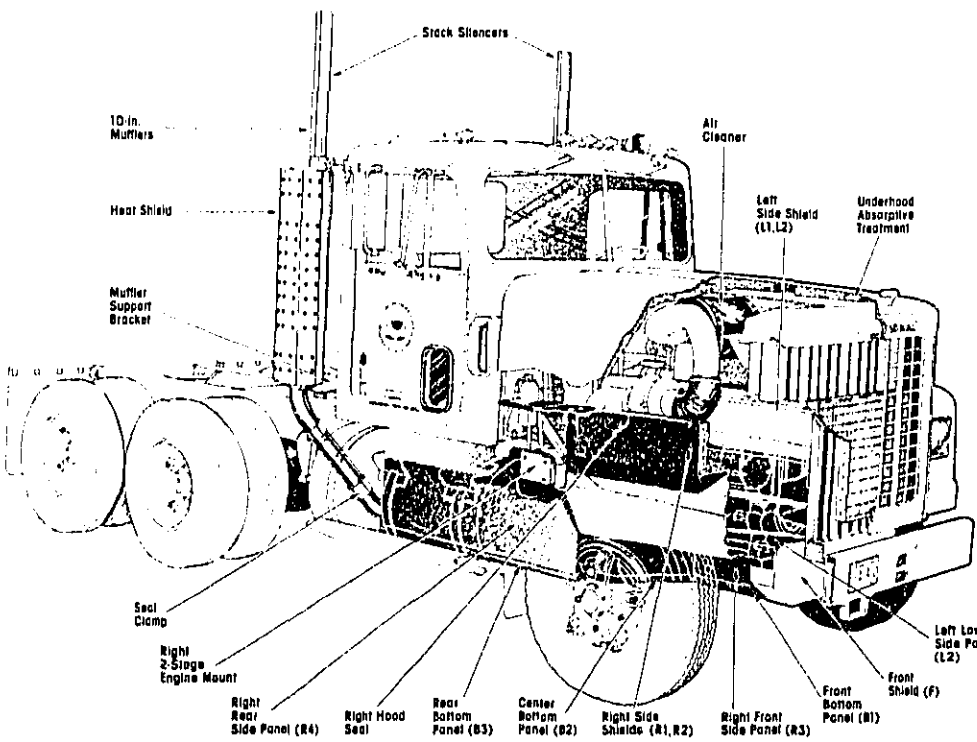


FIG. 3. NOISE CONTROL TREATMENTS INSTALLED ON INTERNATIONAL HARVESTER F-4370.

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

The specific enclosure components are described in Table 3.

TABLE 3. DESCRIPTION OF ENCLOSURE NOISE TREATMENTS.

Designation	Description
L1, R1	Left and right forward side shields above the frame rail
L2, R2	Left and right aft side shields between the firewall and L1 and R1
L3, R3	Left and right side panels of the bellypan forward of the firewall
L4, R4	Left and right side panels of the bellypan between the firewall and the back of the cab
B1, B2, B3	Panels forming the bottom of the bellypan
F	One-piece enclosure sealing the space between the bottom of the radiator and panel B1

Panels L1, R1, L2, and R2 are attached to the frame rail and together seal the space between the inner fenders and the frame rail from the radiator to the firewall. Below the frame rails, panels L3 and R3 form the side walls of the bellypan forward of the firewall. Aft of the firewall to the back of the cab, panels L4 and R4 perform the same function. Panels B1, B2, B3, and F close the bottom of the bellypan from the radiator to the back of the cab.

Two-Stage Engine Mounts

BBN converted the two original single-stage rear engine mounts to two-stage mounts in order to reduce structureborne vibration from the engine and transmission. This conversion was accomplished by making two modifications to the original mounts. First, the isolator bracket that bolted to the bottom surface of the flywheel housing bracket was moved and bolted to the top surface of that bracket. Second, the holes in the frame rail bracket were enlarged to accept rubber isolators. A 12-lb steel block, the largest that could be accommodated, was then fabricated to fit in the resulting space and act as a blocking mass. The same types of isolators as those used in the original single-stage mount were used here, two above the mass in the isolator bracket and two below it in the frame rail bracket. Bolts passed through the isolators into tapped holes in the mass. The assembly is shown in the photograph of Fig. 4.

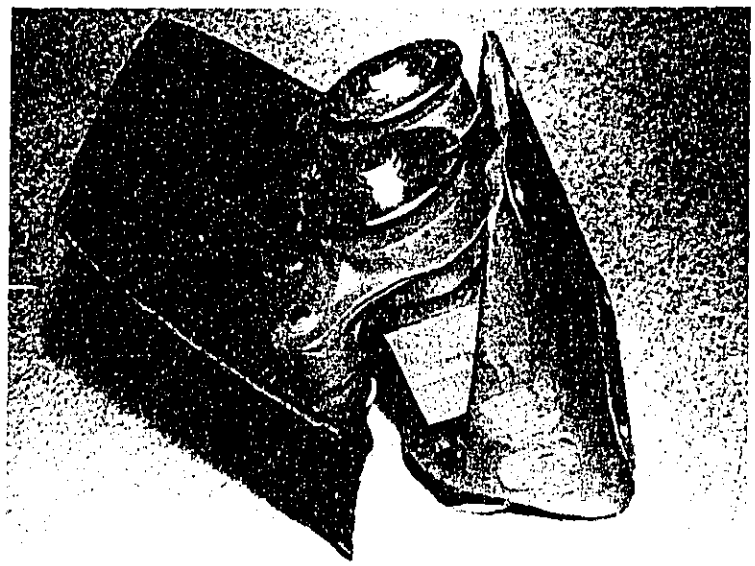


FIG. 4. TWO-STAGE ENGINE MOUNT.

3. FIELD TEST OPERATIONS

The field test of the quieted IH F-4370 was conducted from June 1981 to November 1981 by the Coca-Cola Bottling Company of Northampton, Massachusetts. 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 Coca-Cola Bottling Company of Northampton, Massachusetts (Coke) was selected as the operator of the quieted IH F-4370. This selection was based on several factors. First, Coke was only two hours away from BBN's Cambridge headquarters. Other operators in the Demonstration Truck Program were located in Oklahoma and Arkansas, and this made it difficult for BBN to monitor on a regular basis the condition of the truck, and in particular the noise control treatments.

Second, Coke had an IH F-4370 that would be a basis of comparison for the quieted IH. There were some specification differences between the quieted and comparison vehicles, but these were judged to be minor. Moreover, operations and maintenance data were available for the comparison vehicle.

In addition, Coke had an excellent service operation. The maintenance facility was relatively new and fully equipped. The operation was well managed and it was obvious that both administrative and maintenance personnel were pleased to be able to participate in the field test.

The Coca-Cola Bottling Company of Northampton serves a large portion of New England. Products are bottled in the Northampton plant and shipped to regional distribution centers in Keene, New Hampshire, and Rutland, Vermont. Local deliveries are then made from the regional distribution centers.

The quieted F-4370 operated on one of the company's standard routes - nightly round trips from Northampton to both Keene, New Hampshire and Rutland, Vermont, a total distance of 331 miles. The route is shown in Fig. 5. The truck changes trailers at each distribution center, leaving a trailer of new products and returning with a trailer of empty bottles. However, it occasionally carried some products inbound for purposes of redistributing inventory. Extra trips to either Keene, Rutland, or another distribution center in Pittsfield, Massachusetts were sometimes made, particularly during the summer months when the market for soft drinks is at its peak.

The quiet F-4370 is one of three F-4370's operated by Coca-Cola. A 1976 F-4370 with a Cummins 350 engine had been making the Northampton-Keene-Rutland run for the past several years and provided a basis for comparison. Mileage, fuel, payload, and maintenance records for the comparison F-4370 were assembled by the staff at Coke.

Procedures were developed to monitor the fuel, payload, and maintenance for the quieted F-4370 and to provide comparable data for the untreated F-4370. Mileage, fuel consumption, and payload were tabulated weekly by Coke's Supervisor of Fleet Maintenance. The information was entered on a Weekly Operations Summary, shown in Fig. 6. These summaries were then sent monthly to BBN where they were reviewed and used to prepare the information presented in this report. Maintenance costs were determined from information on the Maintenance Information Summary, shown in Fig. 7. This summary was prepared by Coke each time the vehicle was formally serviced.

Maximum reliance was placed on Coke's management reporting procedures and systems. These procedures were not designed,

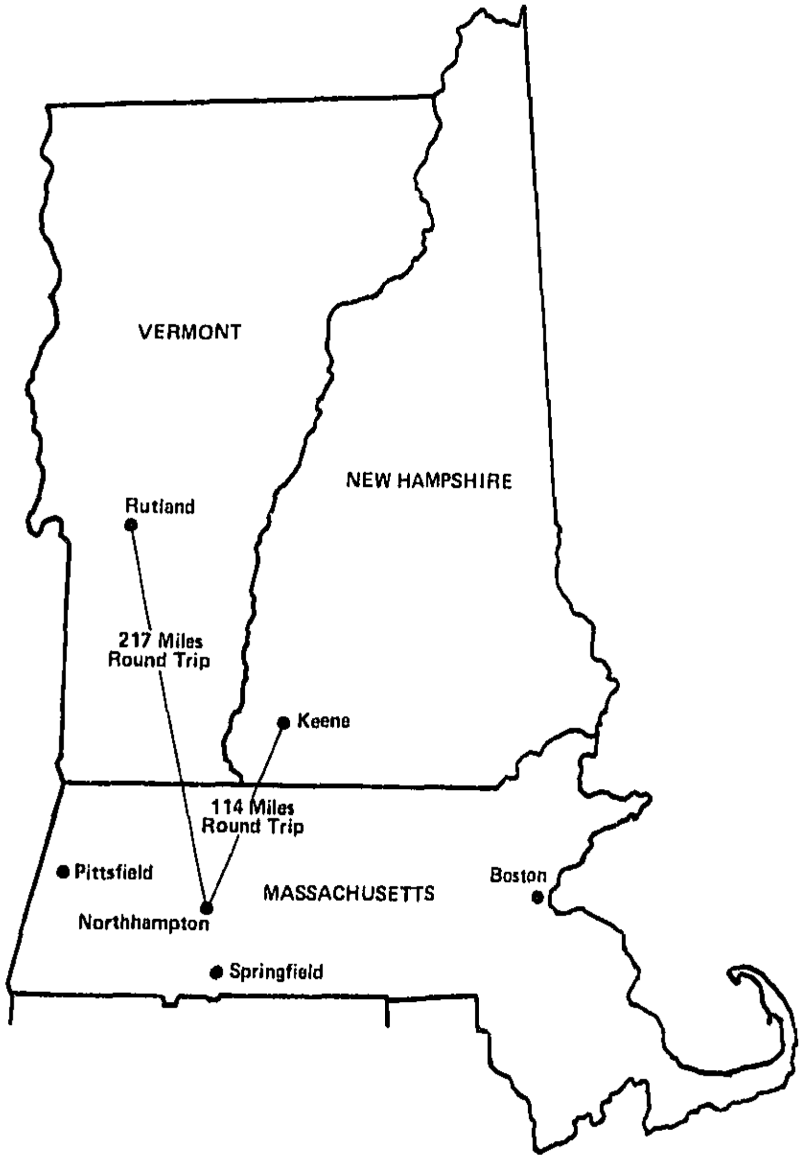


FIG. 5. NIGHTLY ROUTE FOR QUIET F-4370.

WEEKLY OPERATIONS SUMMARY

EPA QUIET TRUCK

WEEK ENDING ___/___/8__ (mo / day / yr)

I. MILEAGE AND FUEL SUMMARY

Trip No.	Date	ODOMETER Beginning	ODOMETER Ending	Miles Travelled	Fuel Used (gals)	MPG	Engine Oil Added (qts)
1							
2							
3							
4							
5							
6							
7							
			TOTALS:				

II. PAYLOAD DATA (Entries in ______________)

Trip No.	Keene		Rutland		Other	
	To	From	To	From	To	From
1						
2						
3						
4						
5						
6						
7						
TOTAL						

Prepared by: ____________________

ATTACH DRIVER TRIP RECORDS

Date Prepared: _____/_____/_____

FIG. 6. WEEKLY OPERATIONS SUMMARY SHEET.

EPA TRUCK MAINTENANCE INFORMATION SUMMARY

DATE OF SERVICE: ___/___/8___
mo day yr

SHOP TICKET: ____________

ODOMETER READING: ____________

	Regular Maintenance	Noise Control Maintenance
In-House Labor (hours)		
In-House Parts ($)		
Outside Repairs ($)		

ATTACHED DOCUMENTS (CHECK)

- ☐ Shop Ticket
- ☐ Shop Ticket Addendum
- ☐ Outside Repair Bill

BBN Use only
Regular $:
Noise $:
Panels Removed:

PREPARED BY: ____________

DATE PREPARED: ___/___/___

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

FIG. 7. EPA TRUCK MAINTENANCE INFORMATION SUMMARY SHEET.

however, to capture information on the noise treatments, and particularly their impact on routine maintenance. A supplemental form, Shop Ticket Addendum, was designed and supplied to Coke 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.

3.2 Field Test Operations, Mileage and Payload

The quieted IH F-4370 entered formal fleet service June 23, 1981 and continued operating until November 20, 1981, when it returned to Cambridge for post-service evaluation. It accumulated 35,778 miles during this 5-month period, an average of 7156 miles per month.

The vehicle left BBN for Northampton on June 15th with an odometer reading of 5098 miles. Coke spent the next several days preparing the vehicle for service. During this time, Coke installed a fifth wheel and an air dryer, and thoroughly serviced the air conditioner. The vehicle made its first run on June 23rd, hauling a 44,500 lb payload outbound. As we describe below, the vehicle continued to operate in this manner for the next five months. The vehicle was in constant service for these five months with the exception of one week in August when the Northampton plant closed for vacation.

Monthly and cumulative mileage is presented in Table 4.* The entries for June and November reflect the fact that the vehicle operated during only part of the month. The intense use

---

*The vehicle operated for five months, June 23rd to November 20th. Table entries throughout this and remaining sections list six months - June through November. The monthly entries for June and November are for the last week and a half of June and the first three weeks of November, respectively. Data for the comparison vehicle are reported on the same basis.

SHOP TICKET ADDENDUM

Treatment Identifiers - IHC F - 4370 Date:____/____/8____

VIEW OF TRUCK

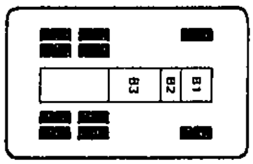
DESCRIPTION OF COMPONENTS

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

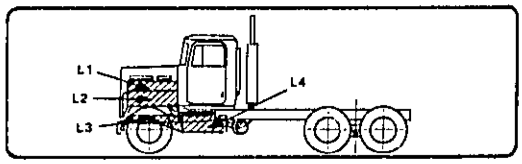
R1: Right Vertical Assembly & Shell
R2: Right Vertical Panel Above Frame Rail
R3: Front Vertical Panel Under Frame Rail
R4: Aft Vertical Panel Under Frame Rail
R5: Sound Absorptive Package on Aft Vertical Assembly

L1: Left Vertical Assembly & Shell
L2: Left Vertical Panel Above Frame Rail
L3: Front Vertical Panel Under Frame Rail
L4: Aft Vertical Panel Under Frame Rail
L5: Sound Absorptive Package on Aft Vertical Assembly

BOTTOM



SIDE



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.

during September was the result of daily trips to Pittsfield during the last week of the month in addition to the normal Keene-Rutland route.

TABLE 4. MONTHLY MILEAGE SUMMARY
IH F-4370.

Month	Monthly Mileage	Cumulative Mileage
June	2,636	2,636
July	7,940	10,576
August	5,686	16,262
September	8,425	24,687
October	6,500	31,187
November	4,591	35,778

The monthly operating pattern of the quieted F-4370 is summarized in Table 5. The vehicle made 104 trips during the 5-month period, or approximately 5 per week. A trip is defined as operations in a 24-hour period. The truck generally operated nightly on the Keene and Rutland routes. Sometimes it would also operate between Northampton and Pittsfield during the day. The nightly route occasionally varied with, for example, two runs to Rutland and none to Keene. The actual mileage for the Northampton-Keene and Northampton-Rutland round trips, the truck's normal route, is 331 miles. This compares to the truck's average trip length of 344 miles. Average trip length dropped in October and November because the truck often was making nightly trips to Pittsfield, in place of either Keene or Rutland.

The F-4370 consistently had the largest payloads of any of the vehicles in the Demonstration Truck Program. The average payload on outbound segments, i.e., leaving Northampton with a full trailer of products, was 42,777 lb. Payload on inbound

TABLE 5. MONTHLY OPERATIONS SUMMARY
IH F-4370.

Month	No. of Trips	Average Trip (mi.)	Aver. Payload out (lb)	Aver. Payload in (lb)
June	7	377	43,723	18,597
July	20	397	44,276	15,780
August	15	379	42,698	12,125
September	24	351	40,870	10,661
October	23	283	42,023	11,457
November	15	306	43,571	12,743
TOTAL	104	344	42,77	12,825

segments, i.e., returning to Northampton with a trailer of empty bottles or products for redistribution, was 12,825 lb. Outbound payloads were largest during the summer months, when the demand for soft drinks is at its peak. This pattern was also true for inbound payloads. Coke reported payload, not GVCW, the overall weight of the tractor, trailer and payload. GVCW can be estimated because the weight of the truck , 16,020 lb, and the weight of trailers, 11,000 to 13,000 lb, is known. Assuming 12,000 lb as the weight of the typical trailer, average GVCW is estimated to be 70,797 lb outbound, and 40,845 lb inbound.

The regular nightly service and large payloads attest to the operating performance of the quieted F-4370. The noise control treatments had no adverse impact on operations. The vehicle never missed a scheduled run and the 332 lb of noise control treatments never displaced any payload. The vehicle's regular driver said he was pleased with its performance and did not observe any instance where the treatments had an adverse impact on normal operations. The driver was, in fact, very pleased with the vehicle, noting it was the quietest truck he had ever heard. He compared its interior noise to that of a pickup truck.

The normal operating pattern of the quieted F-4370 is also evidenced by the entries in Table 6, which show mileage and payload for the quieted vehicle and the comparison F-4370. Mileage for the quieted F-4370 and the comparison F-4370, Unit 366 in Coke's fleet, was roughly comparable. The comparison truck accumulated 3.4% more miles over five months. The payload entries show that the quieted F-4370 averaged slightly more payload, both outbound and inbound, over the comparison period, but the differences are small, as shown in Fig. 9. The quieted unit's payload was 3.3 and 4.7% above the comparison unit's payload on outbound and inbound segments, respectively.

TABLE 6. COMPARATIVE MILEAGE AND PAYLOAD.

Period	Mileage		Outbound Payload		Inbound Payload	
	Quiet	Comparison*	Quiet	Comparison†	Quiet	Comparison†
June	2,636	2,447	43,723	41,471	18,597	11,000
July	7,940	8,192	44,286	41,440	15,780	12,552
August	5,686	7,139	42,698	41,323	12,125	11,943
September	8,425	6,227	40,870	41,511	10,661	12,136
October	6,500	7,948	42,023	41,302	11,457	13,016
November	4,591	5,033	43,571	41,481	12,743	11,741
Total Period	35,778	36,986	42,777	41,400	12,825	12,252

*Comparison period June to November 1980.

†Comparison period June to October 1976.

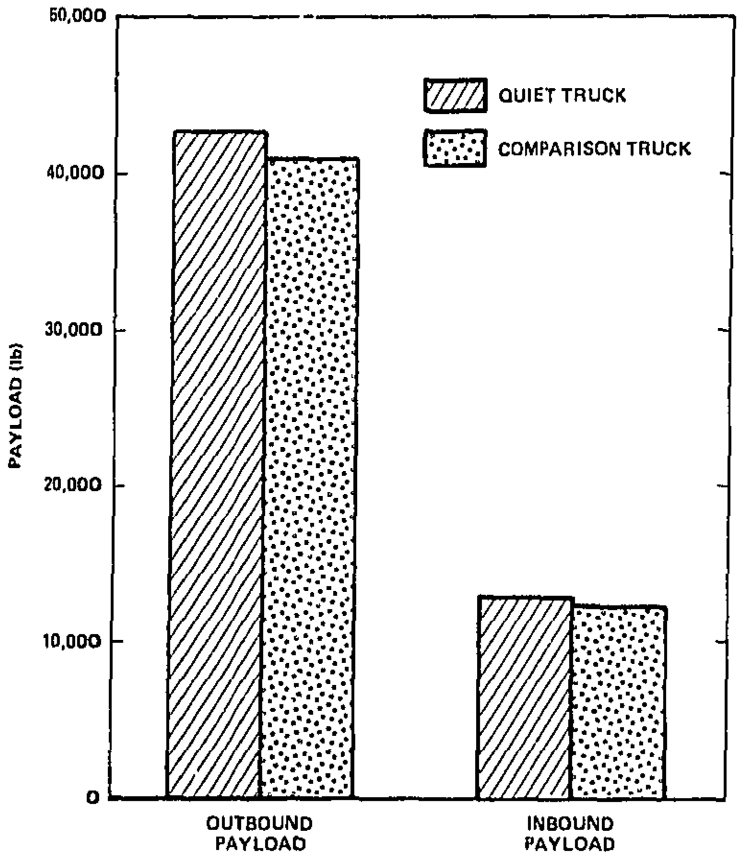


FIG. 9. COMPARATIVE PAYLOAD.

While the quieted F-4370 was only in field testing for five months, all the data, both for it and a comparison vehicle, as well as the driver's comments, indicate that the vehicle's noise control treatments did not adversely affect the vehicle's operating performance.

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 at two locations before the truck entered service, and after the vehicle operated for approximately five months. The first measurement was made by BBN before the truck left its Cambridge facility. The vehicle then went to the General Motors facility in Michigan, where it was displayed with two of the other trucks in the Demonstration Truck Program during a conference sponsored by the Motor Vehicle Manufacturers Association and EPA. At that time, GMC (with BBN and EPA concurrence) noise-tested the vehicle. The truck then returned to BBN and was ultimately delivered to the Coca-Cola Company in Northampton, Massachusetts for operational testing.

Table 7 summarizes the data acquired at these intervals. The data cover a range of 1.4 dBA over 10 months and 40,000 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. However, the Ford and GMC trucks in the program also exhibited reduction in noise during the early part of their field tests.

4.2 Component Durability

When the vehicle was returned to BBN it was inspected to evaluate the durability of the treatments installed. In general, the treatments maintained their integrity. There were no signs of deterioration of the exhaust system, any of the enclosure panels, or the two-stage engine mounts.

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

Date	Location	40 CFR 205 Level (dBA)
Jan. 27, 1981	BBN - Cambridge	72.7
March 2, 1981	GMC - Milford Proving Ground	71.9
Nov. 24, 1981	BBN - Cambridge	71.3

Notable exceptions were failures of various latches and fasteners, which have been chronic problems on other trucks as well. Figure 10 shows that the hook is missing on the metal latch used to hold the hood securely in place. It is believed

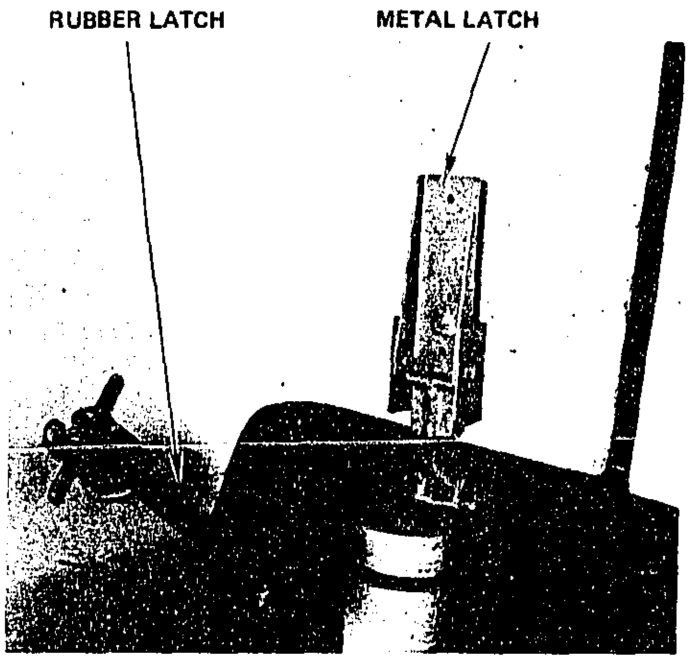


FIG. 10. VIEW OF LEFT SIDE OF HOOD WITH METAL LATCH IN UP (i.e., OPEN) POSITION TO REVEAL MISSING HOOK.

that this adjustable latch was simply tightened too much, and a new hook will be installed.

The quarter-turn fasteners used to support the bottom panels were found to be unreliable. The retaining ring often broke and allowed the fastener to fall out of the panel. The operator replaced these fasteners with the rubber latches used by the manufacturer to hold the hood down, as shown in Fig. 10. Figure 11 shows one of these rubber latches after it was installed on the rear bottom panel. As shown in Fig. 12, the rubber fits into a bracket mounted to the bottom panel. Thus far, these latches have been found to be durable.

A P-seal was used to seal the hood to the left and right side shields (see Fig. 17 of Ref. 3). Figure 13 shows that the relative motion of the hood with respect to the seal caused it to wear. As material wears away, the pressure on the seal will decrease. Therefore, the rate of wear is also expected to decrease.

The unfaced fiberglass installed under the hood showed signs of deterioration. Figure 14 shows the underside of the hood tipped forward when viewed from above the engine. On the panel in the upper left corner of Fig. 14, slots may be observed adjacent to the fasteners. These slots developed as the panel moved downward. The broad heads of the fasteners in one of the center panels appear to be sinking into the fiberglass as it pulls away from the hood. Dirt had built up somewhat on the forward panels (in the bottom of Fig. 14) but hardly at all on the rear panels.

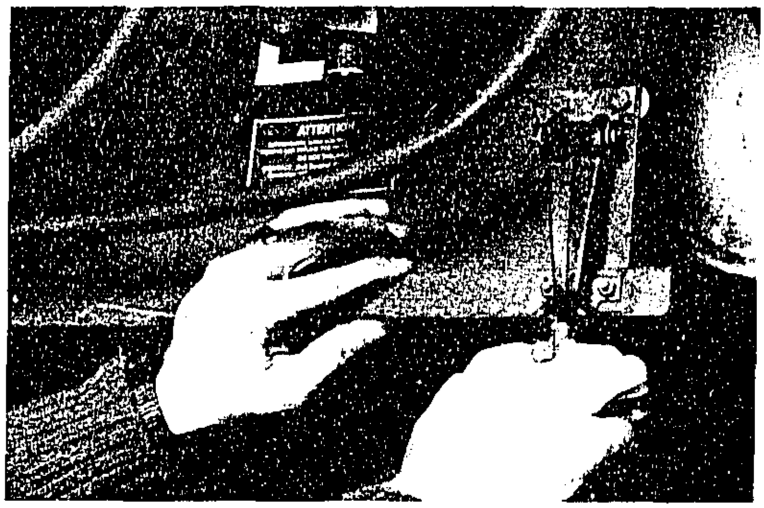


FIG. 11. RUBBER LATCH USED TO SECURE REAR BOTTOM PANEL (B3).

FIG. 12. BRACKET FOR RUBBER LATCH.

FIG. 13. LEFT SIDE SHIELD (L1) SHOWING WEAR ON THE P-SEAL.

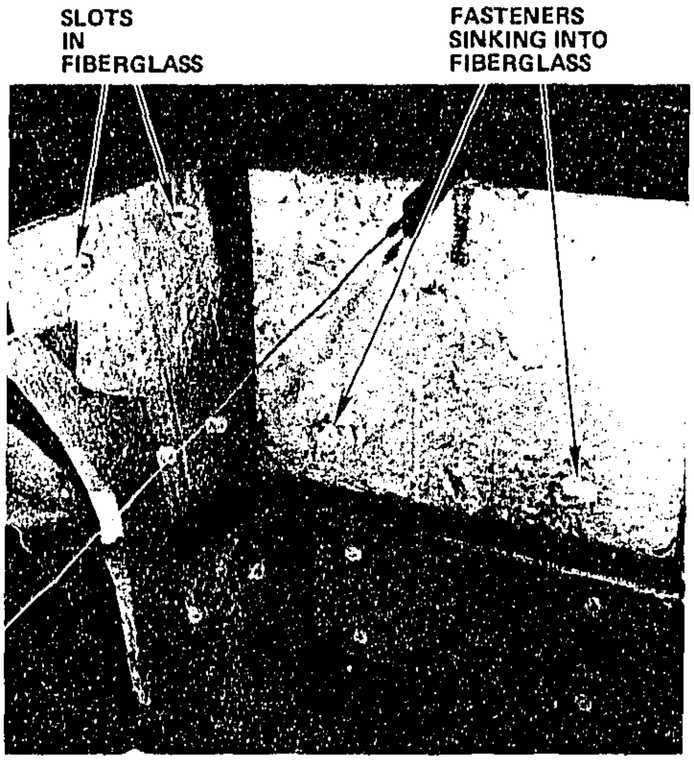


FIG. 14. VIEW OF UNDERSIDE OF HOOD SHOWING CONDITION OF UNFACED FIBERGLASS.

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 332 lb [1]. Using this value in the above equations gives an expected change in fuel consumption of 4.81×10^{-4} gal/mi. This represents 0.23% of the fuel consumption of 0.205 gal/mi determined from the field test.*

To estimate the effect of backpressure, consider the relationships between fuel efficiency and backpressure illustrated in Fig. 15. 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. 15 and will be used for our estimates.

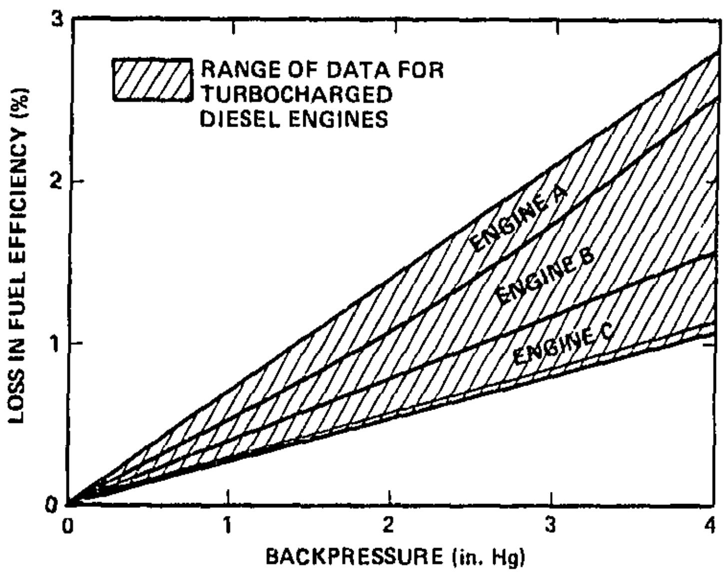


FIG. 15. RELATIONSHIP OF DIESEL ENGINE FUEL EFFICIENCY TO EXHAUST BACKPRESSURE.

---

*7349 gallons used for 104 trips totaling 35,776 miles.

The backpressure generated by the original and final exhaust systems, measured under laboratory conditions on a Cummins NTC 350 BC engine rated at 366 hp, were 1.25 in. Hg and 2.35 in. Hg respectively. That engine had an exhaust flow of 2280 cfm at a density of 0.0307 lb/ft^3; whereas the quieted truck engine at 350 hp had an exhaust flow rate of 2045 cfm and a density of 0.0307 lb/ft^3. Since pressure drop is proportional to density times the square of the volume flow rate, the values corresponding to the engine in the truck must be adjusted downward by $(2045/2280)^2 = 0.8$. Thus the reduction in fuel consumption owing to the lower backpressure of the final system is expected to be 0.8(2.35-1.25)(0.5) = 0.44%.

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 in Fuel Consumption
Weight	0.23%
Backpressure	0.44
Net	0.67%

5.2 Field Data Analysis

The quieted F-4370 achieved fuel economy of 4.868 miles per gallon (mpg) during the five-month field test. This estimate is based on 35,778 miles of service and 7,349 gallons of fuel. Monthly fuel consumption, presented in Table 8, ranged from 5.118 to 4.733 mpg. There was a downward trend in fuel economy over the first three months and then it stabilized at approximately 4.75 mpg.

Table 8 also presents fuel economy for the comparison truck. The comparison period is June to November 1976, when Unit 366 was in its first months of service. The comparison vehicle averaged only 4.193 mpg, or approximately 14% lower fuel economy. The 4.193 estimate is based on 45,440 miles of service and 10,838 gallons of fuel. The monthly entries show that the comparison unit consistently achieved lower fuel economy than the quieted unit.

TABLE 8. COMPARATIVE FUEL ECONOMY.

Month of Service	Quieted F-4370 MPG	Comparison F-4370 MPG
June	5.118	4.495
July	5.096	4.408
August	4.843	4.223
September	4.771	4.166
October	4.758	3.988
November	4.733	4.004
Average	4.868	4.193

There is no obvious explanation for the difference in fuel economy between the two units. There are specification differences that could influence fuel economy. For example, while both trucks have Cummins NTC 350 engines set at 350 hp at 2100 rpm, the quieted truck has a 3.73:1 rear-end ratio, while Unit 366 has a 4.44:1 rear-end ratio. Unit 432 has a 10-speed transmission in comparison to Unit 366's 13-speed transmission. However, payload comparisons, presented in Table 6, show that both vehicles had similar payload patterns. Moreover, the comparison periods are for the early months of operation for each truck.

In short, the quieted F-4370 achieved significantly higher fuel economy than the comparison F-4370 that had operated over the same route. An analysis of this difference is beyond the scope of this program. However, we can conclude that the noise treatments did not appear to have an adverse effect on vehicle fuel economy.

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. Figure 16 shows how one of the panels is removed by releasing quarter-turn fasteners with a screw driver. However, as discussed in Sec. 4.2, these fasteners were found to be unreliable and were replaced with rubber side latches.

With the panels removed, most maintenance points are readily accessed. Figure 17 shows a mechanic lubricating the throwout bearing. The vehicle operator found that the right rear side panel R4 (see Fig. 3) severely restricted access to the oil filter. An access door in the panel would probably have alleviated this problem.

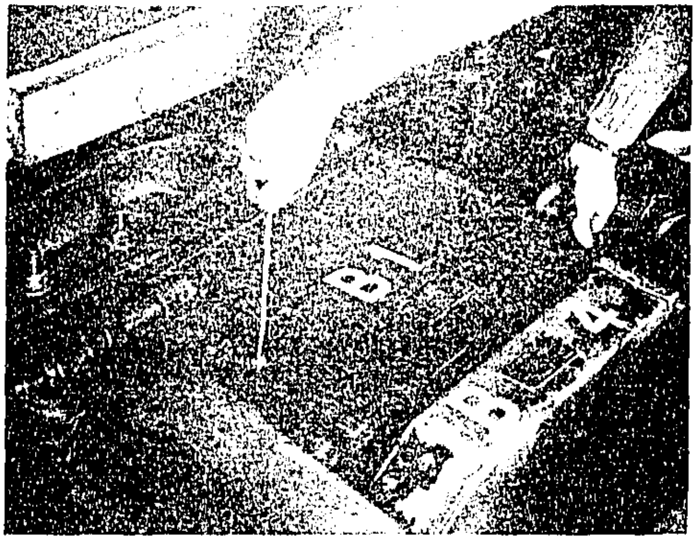


FIG. 16. REMOVAL OF PANEL B1.

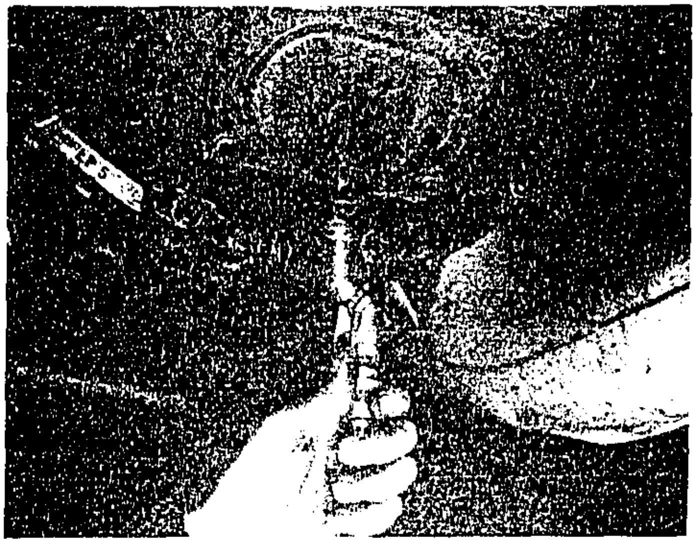


FIG. 17. LUBRICATION OF THROWOUT BEARING.

6.2 Vehicle Maintenance Costs

The quieted F-4370 accumulated $1259.42 of maintenance costs in five months of service. Approximately 8.4% 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.

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 Coke at its Northampton maintenance fcility. Coke's policy is to perform preventive maintenance (PM) to its road tractors every 6000 to 6500 miles. The PM service includes changing the engine oil and the fuel and oil filters. The water filter is changed at every other PM service. The vehicle is lubricated and thoroughly cleaned. Minor repairs and adjustments are also made at each PM service. The cost of regular maintenance was obtained from time-clock cards and Coke's actual parts costs. Labor costs were charged at $17.50 per hour. Oil is charged at $2.95 per gallon, whereas lubricants and miscellaneous parts are included in the overhead portion of the $17.50 labor rate.

There were no outside maintenance costs charged to the quieted F-4370. Coke did have the vehicle serviced outside on several occasions, but in each instance it was to install new equipment on the truck. For example, Coke installed a fifth wheel, air dryer, and an engine brake at a combined cost of over

$3000. These are not operating or maintenance costs, but rather represent initial purchase costs that Coke would have incurred had Coke ordered the vehicle to its own specifications. Therefore, these costs are not reported as "maintenance" costs.

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 estimated from information supplied to BBN by Coke.

Table 9 presents a summary of the maintenance costs charged to the quieted F-4370. Approximately 92% of maintenance costs was for routine, regular service. The remaining 8% was attributable to the noise control costs, with slightly more than half of those costs for the repair of latches on the rear bottom panel of the enclosure.

TABLE 9. CUMULATIVE MAINTENANCE COSTS.

Type of Service	Cumulative Cost (in dollars)
Regular	$1,153.27
Noise Treatment Related	
- repairs	57.37
- panel removal & restriction	48.78
TOTAL	$1,259.42

Monthly service costs are summarized in Table 10. The regular service column includes monthly entries for regular PM service. The monthly PM service typically took three to four hours of labor time and approximately $50 of oil and filters. The high entry in October is for additional labor time for an adjustment to the left rear wheel bearing in addition to the regular PM service for the month. The large costs for November are for several man-days of labor to get the truck ready for winter operations, and for installation of a new water pump. A review of maintenance records for the vehicle and discussions with Coke's Supervisor of Fleet Maintenance indicate that the maintenance of the vehicle was essentially routine and that there were no unusual problems.

TABLE 10. SUMMARY OF MONTHLY MAINTENANCE COSTS.

	Type of Service		
Month	Regular (in dollars)	Noise (in dollars)	Monthly Total (in dollars)
June	120.18	5.83	126.01
July	109.11	63.20	172.31
August	113.24	9.28	122.52
September	96.23	9.28	105.51
October	149.81	9.28	159.09
November	564.70	9.28	573.98
TOTAL	1153.27	106.15	1259.42

Maintenance costs attributable to the noise control treatments fall into three general categories:

- Removal and reinstallation of bottom panels during regular service

- Access restrictions during regular service
- Repairs to the noise control treatments.

There were no instances of repairs to other truck components caused by the noise treatments.

Bottom panels B2 and B3, the middle and aft panels, were removed at each PM service. Removal was required to change the engine oil and to inspect the lower part of the engine compartment. Coke recorded how long it took one of its mechanics to remove and install each of the three bottom panels. These times are presented in Table 11. Note that these times were reported by Coke; these are not BBN times.

TABLE 11. PANEL REMOVAL AND INSTALLATION TIMES.

Panel	Time Required (min:sec) Remove	Install	Total
B1	0:15	0:30	0:45
B2	0:25	0:30	0:55
B3	0:20	0:40	1:00
Total	1:00	1:40	2:40

Coke normally did not remove the front bottom panel for PM service. The removal and installation time for panels B2 and B3 is reported to be 1:55, or approximately 2 minutes. The truck was in for PM service six times. Therefore, an extra 12 minutes was required to remove and reinstall panels B2 and B3 during five months of service. The cost of these 12 minutes is $3.50.

While panel removal costs were minimal, access restrictions attributable to the right rear side panel, R4, were significant. As discussed in Sec. 6.1, this panel interferes with both the oil filter and the oil drain plug. During the first two PM services, the mechanics tried to work around panel R4. They estimated that it took an extra 15 to 20 minutes longer to change the oil filter and drain the engine oil because of the restrictions caused by panel R4. During the last 4 months, the mechanics removed panel R4 during regular PM service in order to get better access to the oil filter. This took an extra 30 minutes each month.

The cost of restricted access to the oil filter is estimated to be $45.21. This reflects 2 hours and 35 minutes of additional time. This access restriction reflects the prototype nature of the BBN treatments and would not be typical of a regular production vehicle.

A final noise-related cost was the repair of broken latches on panel B3. As described in Sec. 6.1, the quarter-turn fasteners installed by BBN proved to be inadequate. Several had already dropped out after two months of service. Coke installed rubber latches at the rear of the enclosure. These latches formed a solid connection between the rear bottom panel and the two side panels L4 and R4. The latches cost $35.49/pair and it took 1 hour and 15 minutes to install them.

Table 12 summarizes all the costs attributable to the noise control treatments. The 2 hours and 47 minutes attributable to panel removal and access restrictions is 6% of the 43.23 hours for regular service charged for the 5-month period. As shown in Table 12, the access restriction caused by panel R4 was the largest single labor cost.

Detailed maintenance cost records were not available for the comparison truck's first year of operation. Coke did not start using time clock records to calculate maintenance costs for each truck until several years ago. Hence, the dollar costs of maintenance for Unit 366, the comparison F-4370, could not be reconstructed. However, the maintenance log for the vehicle did provide a complete maintenance history for the vehicle. We reviewed the log to determine if the quieted F-4370 had a different maintenance pattern from the comparison vehicle.

TABLE 12. SUMMARY OF NOISE-RELATED COSTS.

	Labor Time (hr:min)	Labor Costs	Parts Costs	Total Costs
Panel Removal	0:12	$ 3.50	-	$ 3.50
Access Restriction	2:35	45.28	-	45.28
Treatment Repairs	1:15	21.88	$35.49	57.37
TOTAL	4:02	$70.66	$35.49	$106.15

The maintenance of the two vehicles is essentially the same. The comparison vehicle was in for PM service eight times between June 23, 1976 and November 22, 1976. The service interval for the comparison vehicle was approximately every 6000 miles - virtually the same as the quieted truck. PM service was the same for both vehicles. The only extra repairs for Unit 366 were for replacement of speedometer gear and cable, and for replacement of a front spring leaf. These repairs were made on October 11, 1976.

While the maintenance of the two vehicles cannot be compared on a dollar-for-dollar basis, there is certainly adequate information available to conclude that the two vehicles had similar, if not identical, patterns of maintenance. There does not appear to be any significant difference in maintenance costs between the quieted F-4370 and the comparison vehicle. Moreover, there is no evidence to suggest that the noise control treatments affected the maintenance of the quieted F-4370 in comparison to the unquieted F-4370.

7. SUMMARY AND CONCLUSIONS

The major quantifiable results of the operational evaluation of the IH F-4370 are presented in Table 13. This table shows that the impact of noise control treatments on readily measured parameters was small in most cases and could be made even smaller in others. The noise emission level appears to have become 1.4 dBA lower, from an initial 72.7 dBA to a final 71.3 dBA. The quieted truck actually achieved a better fuel economy than the comparison vehicle, although it was predicted to have a 0.67% increase in fuel consumption. Maintenance costs associated with panel removal and replacement were only a few tenths of a percent of overall maintenance costs for the vehicle. Costs of access restrictions can be attributed to the right rear side panel that interfered with the oil filter and oil drain plug. Treatment repairs relate to the replacement of quarter-turn fasteners with rubber hood latches to support bottom panels. Clearly, both the access and latch problems relate to normal prototype development and could be corrected in design revisions.

TABLE 13. SUMMARY OF QUANTIFIABLE MEASURES OF IMPACT OF NOISE TREATMENT.

Parameter	Change	
	Value	%
Noise Level Change during Operation	-1.4 dBA	-
Fuel Consumption*	49 gal	0.67
Maintenance Costs		
• Panel removal and replacement	$3.50	0.3
• Access restrictions†	$45.28	3.6
• Treatment repairs**	$57.37	4.5

*Predicted value is given. Actual value was not measureable.

†Includes a major interference problem that could be alleviated through installation of an access door.

**Entirely for installation of rubber latches for bottom panel.

During the five months of operational testing, the treatments were found to be reasonably durable. The exhaust system, enclosure panels, and two-stage engine mounts retained their functional and structural integrities. However, there were minor problems with material wear and degradation. In addition to the failures of quarter-turn fasteners, the P-seal on the left side shield showed signs of wear, as did the under-hood sound-absorptive fiberglass. It should be recognized that five months of testing is not sufficient for an adequate test of hardware durability.

In summary, we believe that the field test program has demonstrated that the noise treatments have small impacts on fuel consumption and normal maintenance costs. The program has also identified certain problem areas that are likely to be correctable by modifications to the basic treatment.

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