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TRUCK NOISE X
NOISE REDUCTION OPTIONS FOR DIESEL POWERED INTERNATIONAL HARVESTER TRUCKS
Volume I - Development Work

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16. Abstract

Noise reduction option development work was carried out on two in-service diesel powered IH trucks, consisting of a Cab-over model and a Conventional model with a baseline exterior noise level of 87 dB(A) each. Since no specific noise goals were set, International Harvester established an exterior noise reduction goal of 83 dB(A). Then, for each vehicle, proper noise source identification techniques were applied and major contributors were established. The commerically available source noise reducing components were tested singly, and were selected based upon an optimum evaluation. The selected components were collectively installed on the trucks and cumulative performance in the total truck environment was found to be adequate to meet the established noise level goals.

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PREFACE

As part of its noise abatement effort, the Transportation Systems Center, on behalf of the Office of Noise Abatement, Office of the Secretary, U.S. Department of Transportation, initiated a project to develop noise reduction options for in-use diesel powered trucks and buses. The project was carried out in a number of parallel contracts awarded to (1) PacCar; (2) GM Truck & Coach; (3) Rohr Industries; (4) McDonnel-Douglas in conjunction with White Motor Company; and (5) International Harvester Company (IH). The objective of these contracts was to evaluate commercially available noise reduction modifications and finally to select retrofit kits suitable to reduce exterior noise of in-use vehicles.

This report is a comprehensive assimilation of the data, results and conclusions covering the development phase of the IHC contract along with detailed discussions of the efforts expended in conducting the work. It portrays the present state of art and technology available to reduce the noise of a selected number of IH in-use diesel vehicles. It is hoped that the information contained herein will be helpful to the legislators and owner-operators alike in their respective tasks of legislating and reducing truck noise levels.

International Harvester, in its endeavor to conduct the contract tasks, had to depend upon the voluntary cooperation of many manufacturers of truck components for pertinent information. It is our privileged duty to acknowledge the following manufacturers for their fine cooperation:

1. Donaldson Company, Inc., A Subsidiary of Garlack

2. Riker Manufacturing, Inc.

3. Stemco Manufacturing Co., Inc.

4. Cummins Engine Company, Inc.

5. Detroit Diesel Allison, Division of General Motors Corp.

6. Flex-a-lite Corporation

7. Schwitzer Company, Division of Wallace-Murray Corp.

8. Rockford Clutch, Division of Borg Warner Corp.

9. Horton Manufacturing Company, Inc.

10. Cowl Industries, Division of James B. Carter Limited

11. W. R. Grace and Company

12. Brookside Corporation

13. Northern Tube, Division of Quester Automotive Products.

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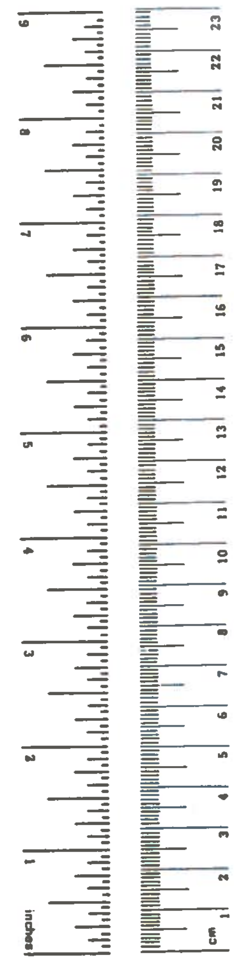
METRIC CONVERSION FACTORS

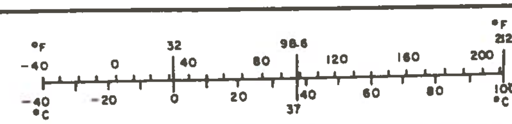
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



1. INTRODUCTION

This report summarizes the testing techniques, data, results and conclusions of the retrofit program to reduce exterior truck noise under Department of Transportation Contract No. DOT-TSC-721. The information contained herein serves the intent of this program to assess, demonstrate and document the noise reduction potential of optimized commercially available exhaust, fan and engine components, and their applicability to existing in-service vehicles.

The work covered by this contract was guided by the results of previous and current DOT development contracts relating to truck noise. Especially helpful were: the IH portion of the Quiet Truck Program for the development of total truck noise technology, DOTOS20222; and, Study of the Parameters Affecting Diesel Engine Intake and Exhaust Silencer Design, DOT-TSC-OST-73-38, and DOT-TSC-OST-73-12, in the selection and evaluation of the commercially available noise reduction components.

1.1 CONTRACT OBJECTIVES

The objectives of this project were as follows:

1. Determine the representative diesel trucks that contributed most to public (and secondarily driver) noise exposure.

2. Determine commercially available components with potential to reduce truck exterior noise.

3. Develop cost-benefit relationship to define optimum combinations.

4. Select noise reduction retrofit packages.

5. Field install and evaluate the selected retrofit packages.

6. Provide noise reduction service bulletins for field use.

7. Publish a report to record project data and conclusions.

1.2 NOISE LEVEL GOALS

No specific noise level goals were called for in the contract since the selection of the trucks to be used for development work was part of the contract effort. It was expected that a significant reduction in vehicle exterior noise level, and consequent reduction in interior noise level, would be possible through application of available technology. A general working goal was set to meet the 86 dB(A) level per SAE J366b, which in effect is the final under 35 mph noise emission regulation for interstate motor carriers.

But at the level of technology currently available, it is necessary to set the target levels about 2-3 dB(A) below the regulated levels in order to assure the compliance in all possible cases. There is variability in noise levels because of component variations, manufacturing tolerances, and different maintenance practices. Therefore IH established an exterior noise reduction goal of 83 dB(A) towards developing noise reducing techniques on test trucks so that a solid 86 dB(A) could be obtained by applying these techniques to other similar model trucks having other engines and exhaust system combinations.

1.3 CONTRACT TASKS

The research and development work was carried out on two basic trucks, designated as primary trucks, with results to be applied to other similar trucks, designated as secondary trucks. Specific definitions of primary and secondary trucks are described in Section 4. The work plan was sequentially itemized into the following tasks:

1. Make truck noise level and population study and select two primary trucks for development work.

2. Establish noise baselines of the unmodified primary trucks.

3. Source identify the major noise contributing components.

4. Evaluate commercially available noise reduction modifications for major noise sources.

5. Establish cost-benefit relationships.

6. Select and make field installations of retrofit kits.

7. Publish bulletins covering noise reduction techniques and specific parts descriptions and installations instruction.

8. Publish a final report recording all support data, results and conclusions.

Contract activities were initiated in January 1974; test and development work started in February, 1974 and continued through November 1974 on the primary trucks, and through May 1975 on secondary trucks when the field installations were completed.

2. CONCLUSIONS

2.1 COF4070A W/NHC250 (PRIMARY TRUCK)

COF4070A is a popular IH cab over model, and NHC-250 is a Cummins, naturally aspirated, in-line 6-cylinder engine.

1. Baseline truck exterior noise level per SAE J-366b drive-by test was 87 dB(A).

2. The baseline truck interior noise level per Bureau of Motor Carrier Safety (BMCS) test procedure listed in regulation was 87 dB(A).

3. Using source identification techniques, the source noise levels were found to be: exhaust 82 dB(A); fan 80 dB(A); engine 81 dB(A); intake 73 dB(A). "Others" sources including transmission, axles, tires etc were estimated to account for a combined level of 75 dB(A).

4. Commerically available exhaust mufflers effectively reduced the baseline exhaust noise level by 4 dB(A).

5. Optimization of fan location, while maintaining the original hardware, provided 2 dB(A) reduction in the fan noise level.

6. Commercially available engine block sound panels, reduced the engine noise level by 1 dB(A).

7. An oil pan enclosure, reduced the engine noise level by an additional 2 dB(A).

8. Air induction system treatment was not necessary since its contribution to total truck noise was not significant.

9. The selected optimum components for exhaust, fan and engine, when collectively installed and evaluated on the truck, provided a 4-5 dB(A) reduction in the total truck exterior noise level compared to the baseline measurement. There was also a 2 dB(A) reduction in the interior noise level with these components installed.

10. Total coverage ranged between 70% and 80% of CO4070A with Cummins and Detroit Diesel in-line 6 cylinder engines in the field built between 1969 and mid 1973.

11. Exhaust resonators inserted between manifold and improved primary muffler reduced pipe shell noise which resulted in a 2 dB(A) reduction in exhaust noise level.

12. Double wall pipe between exhaust manifold and muffler did not produce any measurable change in the noise level when measured with improved muffler and fan and engine modifications.

13. No measurable difference in the fan noise level was found with plastic fans, while cooling was reduced considerably.

14. A steel fan with twisted blades showed significant reduction in the fan noise level; however, cooling was adversely effected.

15. An isolated intake manifold did not show any measurable change in the engine noise level.

16. A rocker arm cover did not measurably reduce the engine noise level.

17. Conversion of the naturally aspirated engine, to a turbocharged engine reduced total exterior noise from 87 dB(A) to 84 dB(A), whereas the interior noise level remained unchanged. This reduction was achieved without any other source noise treatment and the result was a (reduction was not broken down) combined reduction of exhaust and engine noise.

2.2 2000D W/6-71N65 INJECTORS (PRIMARY TRUCK)

Fleetstar 2000D is an IH-Conventional model, and 6-71N65 is a Detroit Diesel, in-line 6 cylinder, scavenged engine with N65 injectors.

1. The baseline truck exterior noise level per SAE J-366b Standard was 87 dB(A).

2. The baseline truck interior noise level per test procedure listed in BMCS regulation was 94 dB(A).

3. Using source identification techniques, the source noise levels were found to be: exhaust 83 dB(A); fan 82 dB(A); engine 81 dB(A); intake 74 dB(A). "Others" sources including transmission, axles, tires, etc, were estimated to account for a combined level of 75 dB(A).

4. A commercially available primary exhaust muffler in conjunction with a "Super Stack" muffler reduced the baseline exhaust noise level by 7 dB(A).

5. The addition of a contoured shroud extension providing 100% fan coverage reduced the baseline fan noise

level by 2-3 dB(A).

6. An engine bellypan for engine treatment provided a 1-2 dB(A) reduction in the baseline engine source noise level. The bellypan also reduced fan source noise by 2 dB(A).

7. Fuel tank mounting straps isolated with rubber (isolating) straps provided a 1 dB(A) reduction in the total truck noise level.

8. The cumulative effects of selected components consisting of primary exhaust muffler and a stack muffler, engine bellypan, isolating straps for fuel tank mounting straps and fan shroud extension provided a 3-4 dB(A) reduction in the exterior noise level of the truck.

9. Total coverage, including primary and secondary trucks, is estimated to range between 70% and 80% of the total 2000D population with in-line 6 cylinder Cummins and Detroit Diesel engines built between 1969 and 1972.

10. Exhaust resonators could not be located between exhaust manifold and primary muffler due to insufficient clearances.

11. Artifically eliminating pipe shell noise did not show any measurable difference in the exhaust source noise, thus indicating that the pipe shell noise was low.

12. Plastic fans showed no measurable change in fan source noise level, while the cooling was reduced considerably.

13. The engine block panels for 6-71N engine provided no measurable reduction in the engine source noise level.

3. TEST PROCEDURES

3.1 TEST SITE

All the truck exterior noise measurements were made on the International Harvester Sound Pad facility that consists of a 100 foot (30.48 M) wide by 200 foot (60.96 M) long diamond with asphalt surface. This diamond is centered on a 1200 foot (365.76 M) long roadway with turn around loops at each end. Microphones are located on both sides of the pad at 50 feet (15.2 M) from the centerline of the path of travel and 4 feet (1.22 M) above the ground. The facility is in full compliance with the test site standards established per SAE J366b. A description of this facility and associated instrumentation is given in Appendix A, "Noise Data Acquisition and Reduction System".

3.2 MEASUREMENT TECHNIQUES

The following sound measurements were made including unweighted and A weighted noise levels:

1. Exterior noise levels including SAE J366b passby; stationary run-up (Idle-max-idle); and constant speed drive-by.

2. Vehicle interior noise levels per BMCS and SAE procedures.

3.2.1 Exterior Noise Measurements

Drive-by exterior noise levels were measured per SAE J366b Standard Practice at a speed equal to or less than 35 mph (56.33 km/h). Constant speed drive-by noise levels were also measured at 80, 90 and 100% maximum governed engine rpm.

Stationary exterior engine run up noise measurements (Idle-max-idle) were taken at full throttle engine acceleration and closed throttle deceleration with engine inertia as the load. These measurements were also made at 80, 90 and 100% of maximum governed engine speed. Practices and procedures required to make these exterior noise measurements are described in Appendices B, C and D.

3.2.2 Interior Noise Measurements

Interior noise levels were measured in accordance with the recommended procedure described in the Bureau of Motor Carrier Safety (BMCS) regulation which is a stationary test as described in Appendix E.

Cab interior noise levels were also measured per SAE J336 acceleration tests. The procedure is given in Appendix F.

3.3 MEASUREMENTS UTILIZED

The sound measurement techniques enumerated above were fully utilized for the baseline truck data as well as the data of the truck with final selected noise reduction kit installed. Sound level meter (Bruel & Kjaer 2203) readings were used to spot check readings taken by the automated instrumentation incorporated into the IH Sound Pad. All instrumentation is certified by Bruel & Kjaer (B & K) for accuracy. In addition, appropriate calibration was performed prior to and after each series of tests.

SAE J366b drive-by test for exterior and BMCS stationary test for interior noise measurements were extensively used for intermediary steps of evaluating the noise reduction modifications.

4. TRUCK SELECTION CRITERIA

The vehicle selection procedure was guided by the project-objective of assessing the noise reduction of a wide cross-section of vehicle designs and design philosophies. The selection of vehicles for the contract work was therefore based upon the representative nature of vehicle designs, the population of each engine-model combination, their noise characteristics, and probable spreadability of noise reduction techniques to other similar vehicles.

4.1 POPULATION STUDY

Motor Vehicle Manufacturers Association (MVMA) information (1973 Motor Truck Facts) pointed out that approximately 50% of the truck population on the road was 6-7 years old. Based upon this information, IH vehicle production figures for the years 1969, 70, 71, 72 and the first half of 1973 were obtained. Lists were then compiled from a computer survey of the trucks built during the established time period which summarized truck sales records by separating them into families of engine-model combinations as shown in Tables 4.1 and 4.2.

4.2 NOISE CHARACTERISTICS

The SAE J366b drive-by exterior noise levels for each truck model-engine combination considered were those prior to 1973 California standards of 86 dB(A). Pre-1973 noise levels of these model-engine combinations with typical exhaust, intake and cab hardware ranged between 86 and 89 dB(A). The range of noise levels shown in Table 4.3 reflect the variation in truck components.

TABLE 4.1, CUMMINS ENGINES TOTAL USAGE BY MODEL - 1969 THRU 73

ITEM	VENDOR DESCRIPTION	CO-TRANSTAR	4200/4300	CONV. 400	FLEETSTAR
1	NHC-250	9442	444	1132	5213
2	NH-230	1066	214	474	2456
3	NTC-335	3979	722	601	55
4	NTC-350	1984	1213	----	----
5	NTC-290	1830	502	38	300
6	NHCT-270 (270 HP)	313	233	----	----
7	NHCT-270 (240 HP)	177	---	147	----
8	NTC-290 (255 HP)	199	---	----	----
9	NTC-350 (320 HP)	138	---	----	----
10	NTC-350 (300 HP)	179	---	----	----
11	NTC-290 (270 HP)	467	---	107	----
12	NTC-290 (300 HP)	892	---	----	----

TABLE 4.2, DETROIT DIESEL ENGINES TOTAL USAGE BY MODEL - 1969 THRU 73

ITEM	VENDOR DESCRIPTION	CO-TRANSTAR	4200/4300	CONV. 400	FLEETSTAR
1	6-71N65	3187	131	546	7760
2	6-71N60	172	---	---	603
3	8V-71N50	270	---	---	----
4	8V-71N55	1750	1056	1218	----
5	8V-71N60	2063	265	596	----
6	8V-71N65	12892	2258	1033	----
7	8V-71NT, N-70	339	---	---	----
8	8V-71TV, N-75	569	366	---	----
9	8V-71NT, N-65	64	---	---	----

4.3 SPREADABILITY

The applicability of results developed under the contract on two basic trucks to same model similar engine combinations as well as to other similar vehicles is called spreadability. In evaluating the spreadability or the extrapolation possibilities, the primary consideration was to be able to apply the noise reducing techniques developed on test (primary) trucks to the same model trucks with other engines and exhaust configurations. In an attempt to summarize this information, a population factor was introduced that was dependent upon primary and secondary extrapolation population. A difficulty factor was also introduced that was a judgment number based purely upon knowledge and previous experience. It was assigned to each model-engine combination under study so that a low rating indicated less noise reducing effort required for that particular combination, and vice versa. Hence, difficulty factor was dependent upon subjective evaluation of the probable spreadability and meaningful noise reduction. The population difficulty factor was then obtained by multiplying the population factor with the difficulty factor. This information is indicated in Table 4.3, and served as one of the guidelines for the truck selection.

It can be seen from Table 4.3 that the Group no. 2 was ranked third under population difficulty factor. But the primary truck population of COF4070A with NHC250 engine in this grouping was higher than the primary populations in the groupings ranked first and second under population difficulty factor. Further, the third ranked group had the second lowest rating from the standpoint of noise reduction effort required. In a similar manner, Group no. 3 in Table 4.3 was ranked fourth under population difficulty factor. But, again, the primary truck population of 2000D with 6-71N (N65) engine was higher than those in the groupings

TABLE 4.3 NOISE CHARACTERISTIC, POPULATION & DIFFICULTY FACTOR

GROUP NO.	MODEL	ENGINE	PRE-73 NOISE LEVEL dB(A)	PRIMARY TRUCKS FOR '69-MID '73	SECONDARY A*	SECONDARY B**	POPULATION FACTOR PRIM + A + B/2	DIFFICULTY FACTOR	POPULATION DIFFICULTY FACTOR
	CO4070A	8V71N65	87-88	12892			18960	.3	5688
		8V71N55			1750				
		8V71N60			2063				
1	CONV.400	8V71N55				1218			
		8V71N65				1033			
	42/4300	8V71N65				2258			
	CO4070A	NHC250	85.5-87	9442			22140	.4	8856
		NH230			1066				
		NTC290			1830				
2		335			3979				
		350			1984				
	Fleet-D	NHC250				5213			
		NH230				2456			
	Fleet-D	6-71N65	87-88, 93	7760			10043	.6	6026
		6-71N60			603				
3	CO4070A	6-71N65				3187			
		6-71N60				172			
4	CO4070A	V-903	85-89	3861			4081	1.0	4081
	42/4300	V-903	85-89			439			
	CO4070A	NTC335	85-89	3979			18301	.5	9151
		290			1984				
5		350			1830				
		NHC250			9442				
		NH230			1066				
	2000D	NHC250	87-88	5213			16820	.6	10092
		NH230			2456				
6	CO4070A	NHC250				9442			
		NH230				1066			
		NTC290, 335, 350				7793			

* A - Same Model, Different Engine

** B - Different Model, Same Engine

ranked first and second.

4.4 SELECTION OF PRIMARY AND SECONDARY TRUCKS

Population study, noise characteristic and spreadability consideration discussed in the preceding Sections provided proper perspective to categorize primary and secondary trucks and select the most appropriate engine-model combination for the development work. The general categorization in the selection of trucks for development work (primary truck) is illustrated in Figure 4.1.

The primary vehicles were defined from the standpoint of highest population in the field, typical exterior noise levels and probable spreadability of results to other similar vehicles. The secondary vehicles consisted of the potential candidates for spreadability with same engine but different models, or same model, different engines.

Engineering specifications and Service Parts catalogs were researched for engine-model combinations with major emphasis on exhaust, intake and cooling systems. Besides providing lists of production parts for both the primary and secondary trucks, this information also helped to establish the extrapolation possibility for the secondary trucks.

4.5 CUT-OFF POINT

It was further revealed from the population study that certain engine-model combinations did not significantly impact the sale. After considering all design variations and engine-model combinations, it became clear that 100% coverage was an unachievable task. A cut-off point was then established for any engine-model combination with population density below 2% of the total truck population. This yielded an estimated range of coverage between 70-80% of the total truck population with in-series Cummins

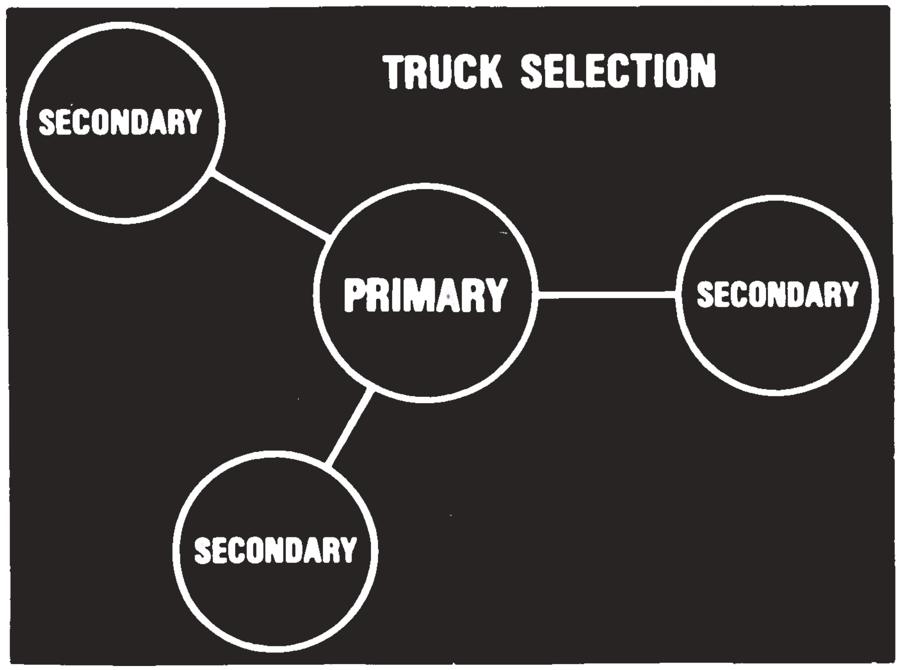


FIGURE 4.1 TRUCK SELECTION.

and Detroit Diesel engines as indicated in Table 4.4.

4.6 SELECTED TRUCKS

Table 4.3 was prepared to present the noise characteristic, the total population of model-engine combinations and potential candidates for extrapolation. The chassis model engine combinations were further arranged in groups to allow coverage of two and four cycle engines with cab-over and conventional chassis designs. The chassis models with 8V-71N engine in Group no. 1 with highest primary truck population were not considered since CO4070A with this engine was selected for Quiet Truck Program. Also, it ranked fairly low under the population difficulty factor. The Group nos. 2 and 3 had the second and third highest primary truck population with population difficulty factor rating of third and fourth respectively. Hence, the primary trucks selected for development work were a COF4070A w/Cummins NHC250 engine and a 2000D Fleetstar w/Detroit Diesel 6-71N-65 engine. The secondary trucks were established by using the cut-off criteria. The spreadability chart in Figure 4.2 shows the primary vehicles in the middle and the satellite secondary vehicles with probable coverage.

The COF4070A is a popular over-the-highway truck used for long haul and/or tanker trailer operation. The Fleetstar D was a popular medium horsepower range diesel powered truck used both for tractor-semi trailer and straight truck operation; production of the Fleetstar D ended on December 20, 1972. Following the selection of primary engine-model combinations, the IH Used Truck Sales organization identified representative, in-service samples of these trucks. Subsequently these trucks were purchased and delivered to IH Truck Division Engineering.

TABLE 4.4, ESTIMATED COVERAGE

ENGINE FAMILY	POPULATION CONSIDERED			% NOT CONSIDERED
	PRIMARY	SECONDARY	TOTAL	
N-SERIES CUMMINS	19309	7793	34517	21.5
6-71N DETROIT DIESEL	10947	603	12399	6.8

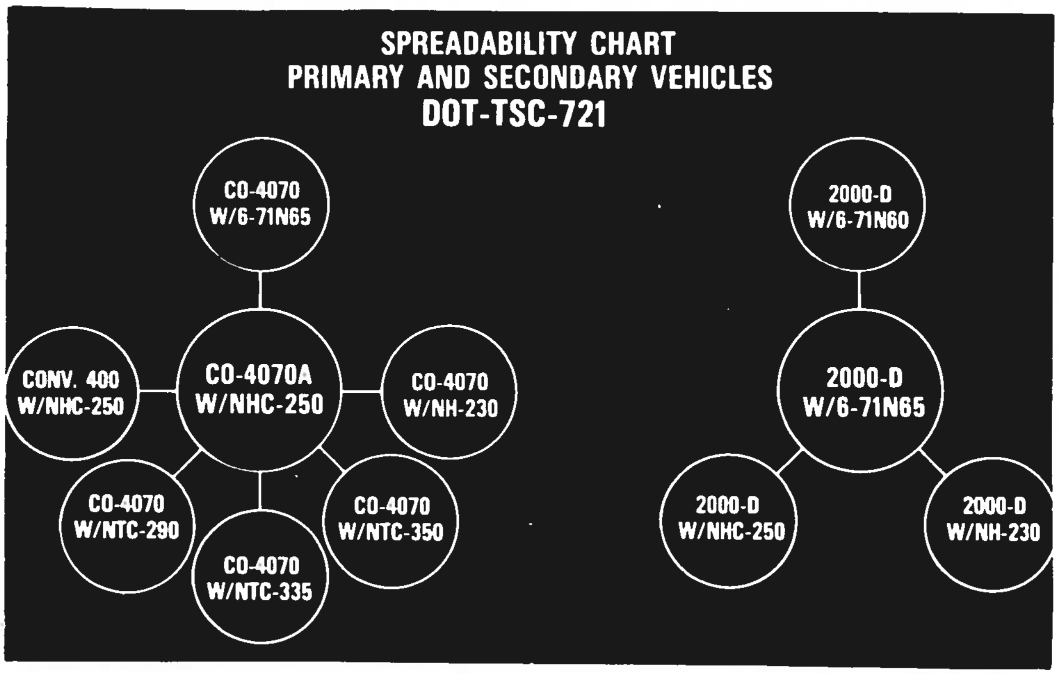


FIGURE 4.2 SPREADABILITY CHART

5. DEVELOPMENT WORK ON COF4-7-A

The description of the major components of the COF4070A first primary truck, is listed in Table 5.1. SAE pass-by runs were made with the as-received vehicle and exterior noise level was found to be 87 dB(A). Interior noise level per BMCS regulation was also 87 dB(A).

A preliminary inspection was then made to determine what would be required to bring this vehicle to a "properly maintained" level in preparation for baseline noise measurement.

5.1 PRELIMINARY INSPECTION

It must be recognized that the first step in reducing the noise of a truck is to bring it to "properly maintained" condition. In order for the retrofit kit developed under this project to be fully effective, it is deemed essential to inspect, detect and correct maintenance deficiencies prior to any modifications. A preliminary inspection may include the following items:

1. All accessory belts;

2. Fan hub-bearing assembly;

3. Scavenger blower assembly;

4. Engine governed speed per manufacturer specifications;

5. Tappets and injectors adjustment;

TABLE 5.1 - BASIC COMPONENT DESCRIPTION OF PRIMARY TRUCK COF4070A

Make:	International Harvester
Model:	Cab Over
Cab:	84 in. (2.13M) Cab-Over-Engine
Wheelbase:	145 in. (3.68M)
GVWR:	73,000 lb. (33,100kg)
Engine:	Cummins NHC-250 Naturally Aspirated Engine
Transmission:	Fuller RT-910 (10 Speed)
Exhaust System:	Single 9 in. (228.6mm) Body Diameter Vertical Muffler, 4.0 in. (102mm) In and Out. IH No. 979541-R91, with Vertical Tailpipe (SVVTP)
Induction System:	Primary Dry Air Cleaner, IH No. 366380-C92 Vertical Intake Pipe.
Fan:	IH No. 362907-Cl, 22.5 in. (571.5mm) Diameter, 6-Blades
Front Axle:	IH FA-139, 12,000 lb. (5443kg) Wt.
Brake System:	Bendix-Westinghouse, Air
Clutch:	Lipe Rollway, 14 in. (356mm) 2 Plate
Rear Axle	Rockwell SLHD 34,000 lb. (15400kg) Single Reduction Tandom
Suspension:	Hendrickson RTE-340
Date Built:	December 1969
Mileage:	295,697 miles (475877KM)

6. Exhaust pipe length per specifications, leakage, etc.;

7. Axles and transmission, unusual gear and bearing noise;

8. Intake system per specifications;

9. Any other components making unusual noise.

The preliminary inspection of the COF4070A revealed that the vehicle had worn-out, improper fan drive belts which permitted slippage near the top end of the engine speed range. New belts were thus installed and belt tension was adjusted. New exhaust system components as well as new intake filter elements were installed. These components were production items obtained from service parts listing. The baseline truck is shown in Figure 5.1.

The primary chassis COF4070A was hence fitted out for baseline noise measurement (where baseline condition is defined as the unmodified vehicle in a suitable condition of repair).

5.2 BASELINE NOISE LEVELS

The baseline noise measurements of COF4070A were taken according to the measurement techniques discussed in Section 3. SAE J366b drive-by tests were conducted along with Idle-max.-speed idle test. The baseline exterior noise level was found to be 87 dB(A). The interior noise level was measured according to the Bureau of Motor Carrier Safety (BMCS) regulation at 87.0 dB(A). Baseline exhaust system back pressure and air intake restrictions were also measured in accordance with the techniques presented in Appendices G & H, and were found to be 0.4 in. (10.16mm) Hg and 7.3 in. (185.4mm) H_2O respectively. The engine manufacturer's

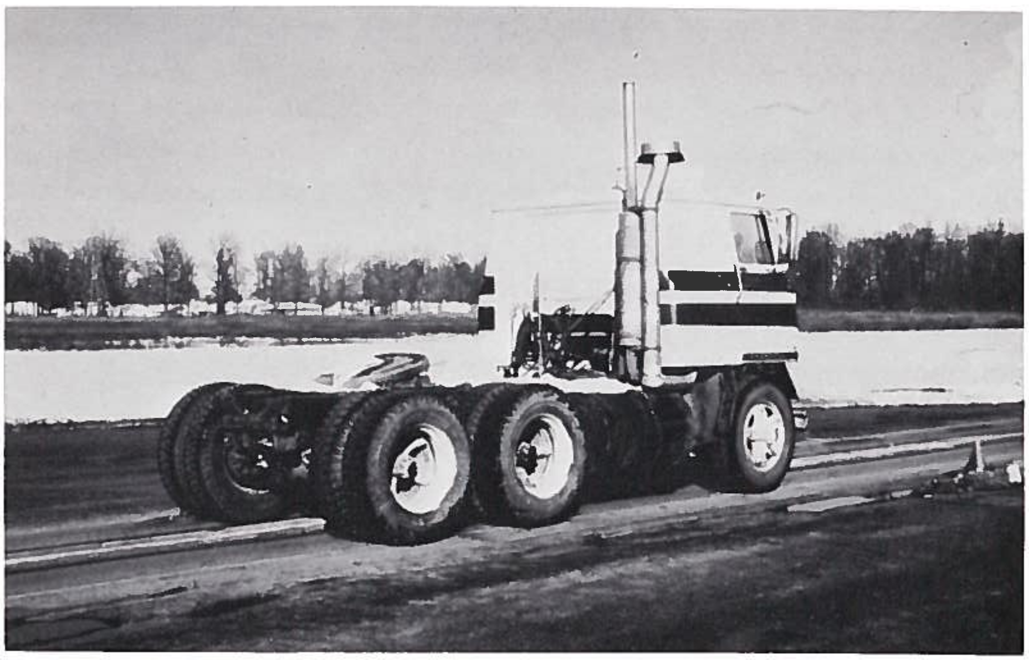


FIGURE 5.1 BASELINE TRUCK - COF-4070A.

specifications are 2.00 in. (50.8mm) Hg and 15.00 in. (381mm) H_2O respectively.

5.3 SOURCE IDENTIFICATION

The basic source identification technique of artificially silencing all the truck noise sources and then restoring each source, one at a time, was modified. In this project the source noise was determined by subtraction after eliminating each source one at a time. To avoid time consuming engine wrapping, engine plus "Others" noise level was then subtracted to obtain the engine source noise level. Although this method is not as accurate as that of fully wrapped vehicles, it was considered satisfactory for the treatment of the noise sources in this program. The source identification technique of artificially quieting all sources, therefore, included engine treatment as adequate means of engine noise suppression, while axle-transmission noise was treated as part of "Others" with tire noise, etc.

5.3.1 Exhaust

The vehicle exhaust system was treated first by installing a super quiet exhaust system on the COF4070A primary truck to eliminate exhaust noise as an identifiable source. The super quiet exhaust consisted of two, large volume mufflers in series, installed in conjunction with an absorbing tailpipe muffler. The muffler and exhaust pipes were wrapped with a layer of absorbing fiberglass material and a layer of vinyl barrier (H. L. Blachford, Inc., Baryfol 20M) material to eliminate radiated noise from muffler pipe and surfaces (See Fig. 5.2). The fan was then removed and drive-by noise level was measured in accordance with SAE J366B Standard Practice. This noise level, subtracted acoustically (a logrithmic process) from the noise level with production

FIGURE 5.2 SUPER QUIET EXHAUST INSTALLED.

exhaust and fan removed, provided exhaust source noise level to be 82 dB(A).

5.3.2 Intake

Intake air cleaner and pipes were wrapped with layers of fiberglass and vinyl barrier material to eliminate shell noise. An absorbing stack cap was also installed to control stack emission as shown in Figure 5.3 SAE pass-by run was made without fan, exhaust and intake artificially silenced to determine intake noise level. This noise level when subtracted from the noise level obtained in the section above with exhaust silenced and fan removed gave the estimated intake noise level to be 73 dB(A).

5.3.3 Engine

The Cummins NHC 250 engine was the power plant in the COF4070A primary development truck. It is a naturally aspirated in-line 6 cylinder diesel engine with a cast aluminum oil pan. In this version of the engine, the cooling fan is mounted to the water pump shaft. The performance curve of this engine is given in Appendix I.

The engine source noise level of 81 dB(A) was determined by subtracting the estimated "Others" sources noise level from the noise level obtained with artificially silenced exhaust and intake and fan removed.

As described in Section 5.3, the engine was not wrapped. Commercially available engine noise suppression panels and covers were applied after silencing exhaust and intake noise. It was felt that adequate engine treatment would render the vehicle sufficiently silent to permit evaluation of exhaust and fan noise modifications.

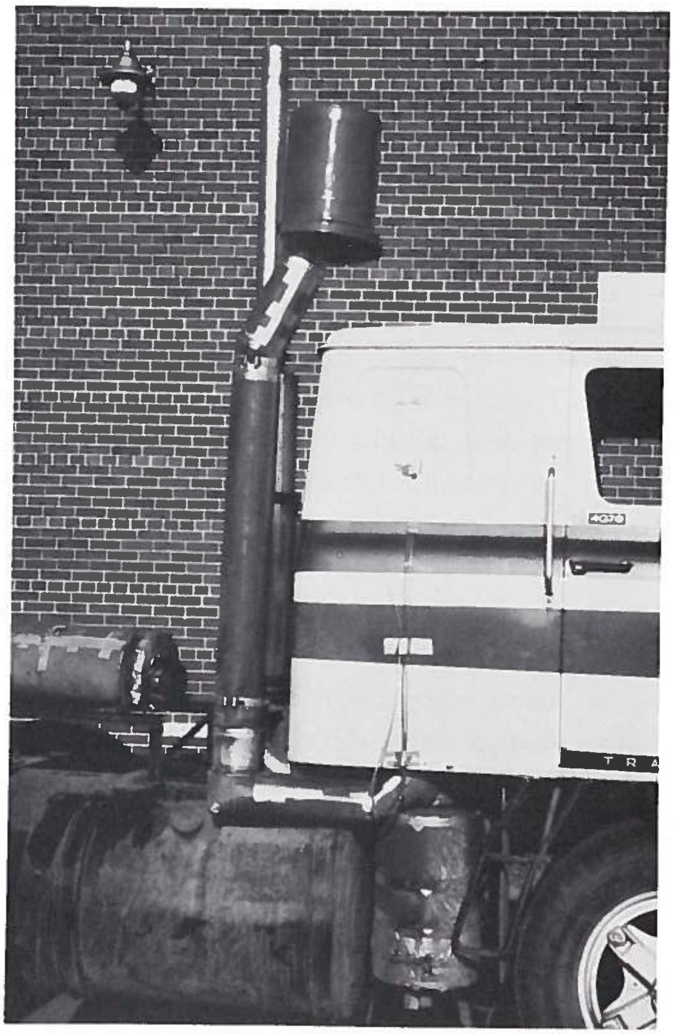


FIGURE 5.3 SUPER QUIET INTAKE INSTALLED.

5.3.4 Cooling System

The cooling system noise elimination was done by simply removing the cooling fan and making a SAE drive-by test. A noise level obtained in Section 5.3.3 with fan exhaust and intake fully silenced and engine partially silenced was subtracted from the noise level of the same condition but without fan, which yielded the fan noise level of 80.0 dB(A).

5.3.5 Source Levels

The final experimentally silenced vehicle noise level was 78 dB(A). In this condition, the exhaust and intake were fully silenced; fan noise was eliminated by removing the fan; engine noise was reduced by utilizing noise suppressing covers and panels. The individual source noise levels for the COF4070A primary vehicle are shown in Figure 5.4.

At the conclusion of the noise evaluation of the commercially available components on the artificially silenced vehicle, the major noise sources were restored to their baseline condition one at a time. SAE drive-by noise levels were taken at each step (of restoration) and source noise levels were calculated again which confirmed the source noise levels obtained in the initial stage described in the preceding sections.

The noise source "Others" consisted of transmission, axles, wind, tires, etc. The source level of "Others" was estimated as follows: first, the transmission noise level was estimated to be 73 dB(A). This estimate was obtained from the results of Quiet Truck Program where the transmission was the same (Fuller RT-910) as that used in COF4070A, second, the coast-by run with the engine shut down showed the "Others" source (except transmission)

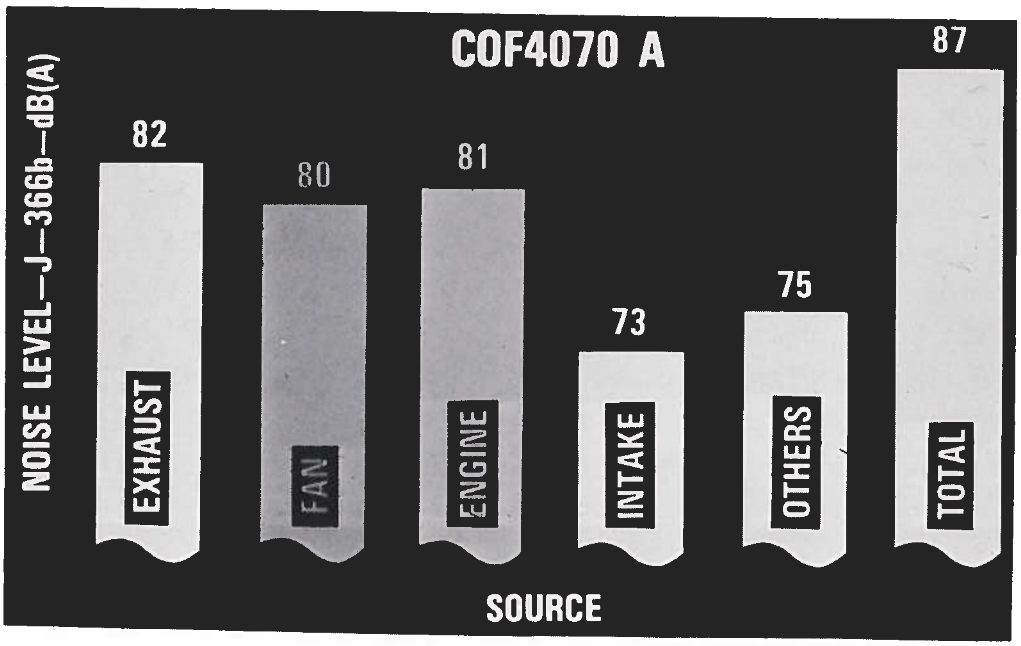


FIGURE 5.4 BASELINE SOURCE NOISE LEVELS.

noise level to be 69 dB(A). These two noise levels were acoustically added to obtain total noise level of "Others" as 75 dB(A).

To better understand the results, the truck noise sources were analyzed by using the three dimensional data. The sound level versus truck position, during a J366b test, was plotted as shown in Figure 5.5. As the throttle was opened at the beginning of the test (50 feet (15.24M)) before microphone) the total truck noise was above 81 dB(A) with exhaust and engine contribution being close to 79 dB(A) and dominating the total truck noise. The exhaust noise increased until about 20 feet (6.1M) beyond the center position and peaked out around 83 dB(A). During the center position of the drive-by test, the exhaust was the predominant source. The engine noise peaked out at 40 feet (12.2M) after the starting position, and decreased slowly and gradually towards the end zone. The cooling fan speed was increasing throughout the measurement zone, reaching maximum at the finishing line. Other sources at this point had reduced and fan noise was predominant.

It may be noted that the individual sources peaked at different points in the measurement zone. Furthermore, different sources were predominant at different positions during the drive-by test. This demonstrates the significance of noise versus position analysis of the total truck noise.

The frequency analysis of the total truck noise at its peak level and the major sources at that point is shown in Figure 5.6. The exhaust noise was dominant at the beginning in the frequency range of 100-250 Hz. The cooling fan then became major contributor around 250 Hz and remained so up to 400 Hz. At that point, exhaust noise came right back up and dominated up to 750 Hz. The engine noise predominated in the range of block resonance frequencies from

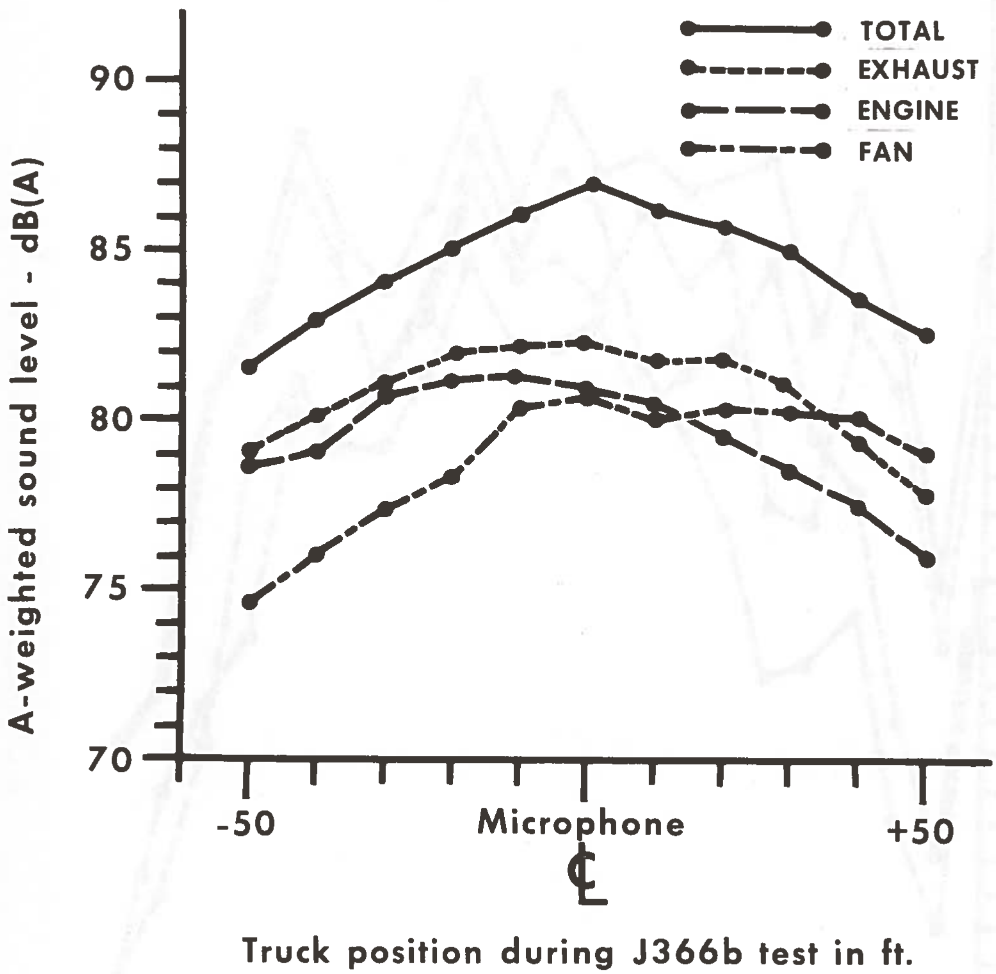


FIGURE 5.5 BASELINE SOURCE & TOTAL NOISE LEVELS VS. TRUCK POSITION.

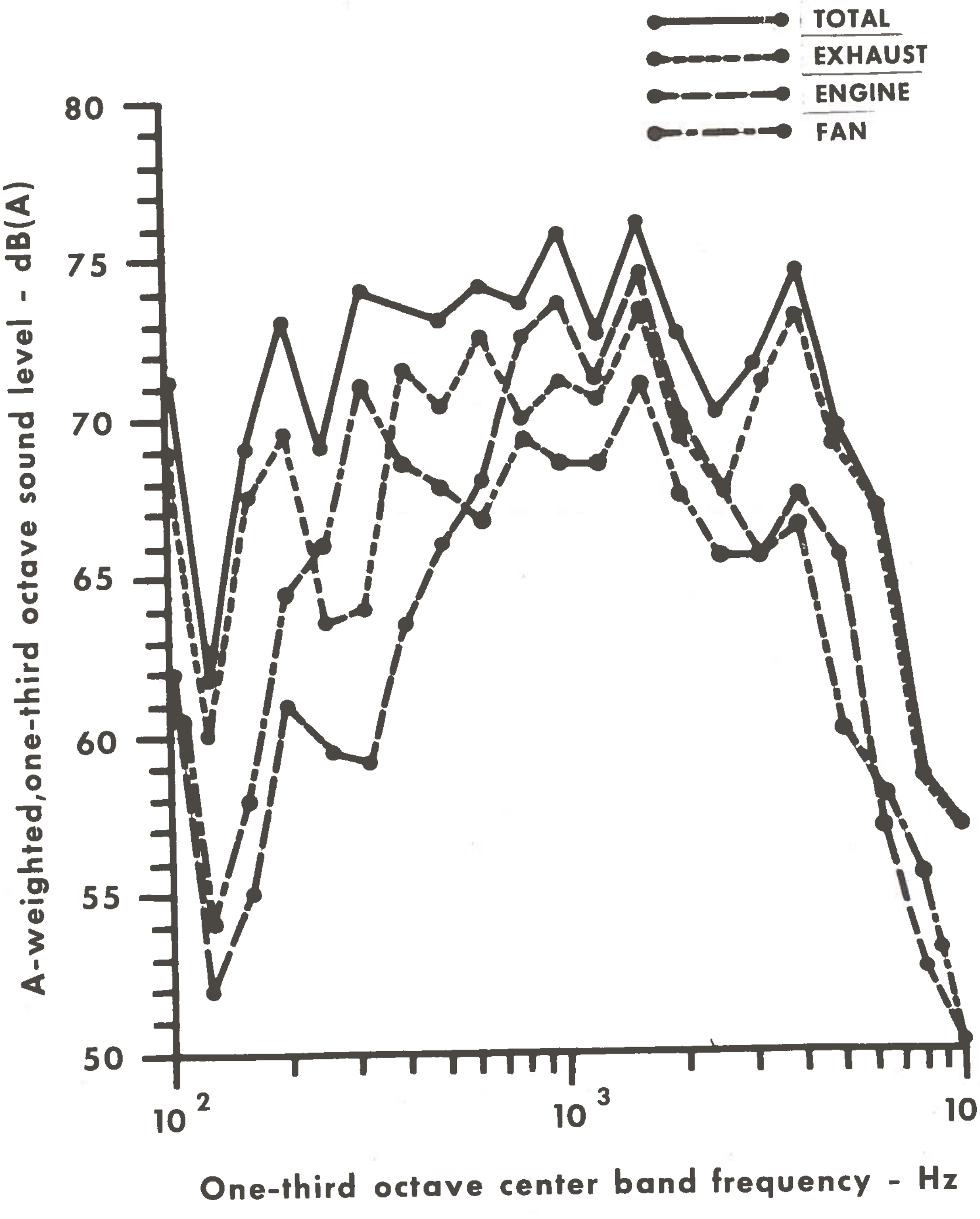


FIGURE 5.6 BASELINE SOURCE & TOTAL NOISE LEVELS VS. FREQUENCY.

750 Hz to 1250 Hz. The engine, exhaust and fan noise sources peaked out between 1250 Hz and 2500 Hz. At the frequency point of 2500 Hz and beyond, the exhaust was the predominant source of noise.

The frequency spectrum further indicated that different noise sources became predominant in various frequency bands. Hence frequency analysis along with noise versus position plot were extensively used in noise source identification and development of modifications under the contract.

5.4 COMPONENT EVALUATION

In the effort to meet the contract objectives of selecting retrofitable, commercially available components for existing in-use trucks, a systematic procedure was established of meeting with the component manufacturers and suppliers, discussing the program in detail, and obtaining their recommendations for modifications to quiet the major truck noise sources. Based upon their recommendations, the appropriate items were procured for subsequent test and evaluation. The contracts were maintained throughout the program to channel the pertinent information back and forth. The suppliers were promptly informed of the test results and their comments were invited.

5.4.1 Exhaust Mufflers and Related Hardware

Various manufacturers of truck mufflers recommended commercially available suitable mufflers for exhaust noise reduction for the model-engine combination under consideration. Department of Transportation reports compiled by Donaldson and Stemco on Exhaust and Air intake Noise (referred to in Section 1) were consulted for further guidance.

The standard exhaust system offered in production with the COF4070A chassis model was a single vertical muffler, vertical tailpipe (SVVTP) with 4.00 in. (102mm) inlet-outlet. Donaldson, Riker and Stemco muffler manufacturing companies supplied their best mufflers for 4.00 (102mm) SVVTP exhaust system on COF4070A with NHC-250 engine primary combination. The specifications on production muffler and recommended noise reducing mufflers are shown in Table 5.2.

Test results were found to be in variance with the muffler manufacturer rating. Reportedly the muffler manufacturer rating procedure generally does not account for pipe shell noise as experienced in the total truck environment. Also, it does not account for leaks in the joints. Hence, the difference between the test results and manufacturer rating of these mufflers in the total truck environment.

5.4.1.1 Donaldson Muffler

Donaldson muffler (No. WTM10-0066) IH No. 549483-C1 showed consistent repeatability of results during SAE drive-by tests by reducing the baseline exhaust noise level of 82 dB(A) to 78 dB(A). This muffler has integral wrap, consisting of absorbing material for wrapping and covered with aluminized steel sheet. As listed in Table 5.1, the body diameter of this muffler is 10.00 in. (254mm) whereas that of the production muffler is 9.00 in. (228.6mm) which warranted redesign of mounting bracketry and relocation of the muffler. The muffler is shown installed in Figure 5.7.

5.4.1.2 Donaldson Premufflers

As mentioned previously, pipe shell noise is one of the major factors in the total exhaust noise. This is due to intense acoustical energy being emitted from the exhaust pipe in the close proximity of the engine. Inserting

TABLE 5.2 MUFFLER EVALUATION

MANUFACTURER (MFR)	MFR/IHC PART NO.	DESCRIPTION	BODY DIA. IN/mm	BODY LENGTH IN/M	OVERALL LENGTH IN/M	EVALUATED NOISE RATING dB(A)	BACK PRESSURE IN/mm HG.	REMARKS
Donaldson	MUM09-0022 / 979541-R91	Muffler	9.00 / 229	44.50 / 1.13	51.00 / 1.3	82	0.8 / 20	Standard Production Muffler
Donaldson	WTM10-0066 / 549483-C1	Muffler	10.00 / 254	43.50 / 1.11	51.00 / 1.3	78	1.4 / 36	Muffler
Donaldson	MPM07-0129 / 467354-C1	Pre-Muffler	7.00 / 178	10.00 / 254	13.00 / 330	76	2.4) / 61)	Pre-Mufflers Evaluated in conjunction w/WTM10-0066
Donaldson	MUM07-0128 / 467092-C1	Pre-Muffler	7.00 / 178	10.00 / .254	13.00 / .330	76	1.6) / 41)	
Riker	9XD405	Muffler	9.00 / 229	44.75 / 1.14	52.00 / 1.32	79	1.9 / 48	----
Stemco	9870	Muffler	10.12 / 257	45.0 / 1.14	51.5 / 1.31	78.5	1.4 / 36	----
Cowl	S40TR	Silencer	---	---	---	80.5	1.2 / 30	----

FIGURE 5.7 WTM10-0066 MUFFLER INSTALLED.

another muffling element between primary muffler and manifold, preferably immediately after the manifold has been effective in reducing pipe radiated noise.

Two Donaldson exhaust premufflers (resonators) were evaluated on COF4070A with primary muffler 549483-C1. The two resonators were fairly close in their effectiveness in reducing about 2 dB(A) from the exhaust noise. The resonator MPM07-0129 construction utilizes a 2.0 in. (51mm) choke whereas the resonator MUM07-0128 utilizes no choke which explains the variation in their respective back pressures. The necessary specifications on these resonators are given in Table 5.1, and installation is shown in Figure 5.8.

5.4.1.3 <u>Double Wall Pipe</u>

Double wall pipe is reportedly considered to be an effective measure to reduce pipe shell noise, and is being recommended by its manufacturers. The effect of double wall pipe was, therefore, investigated during the evaluation of exhaust noise reducing sub-systems on COF4070A.

The exhaust pipe between the manifold and muffler was wrapped with vinyl barrier material to simulate double wall pipe. This simulation was carried out with the optimum primary muffler (549483-C1). The drive-by test indicated about a 2 dB(A) reduction in the exhaust noise level. This encouraging result prompted further investigation, and the Northern Tube, Division of Quester Automotive Products Company, manufacturer of double wall pipe, was contacted for their input in the program. Their engineers and sales manager visited IH and after detailed discussions of the program they were pleased to participate and provide a sample. The sample was procured subsequently and evaluated. Figure 5.9 shows the double wall pipe.

The construction of the double wall pipe sample provided

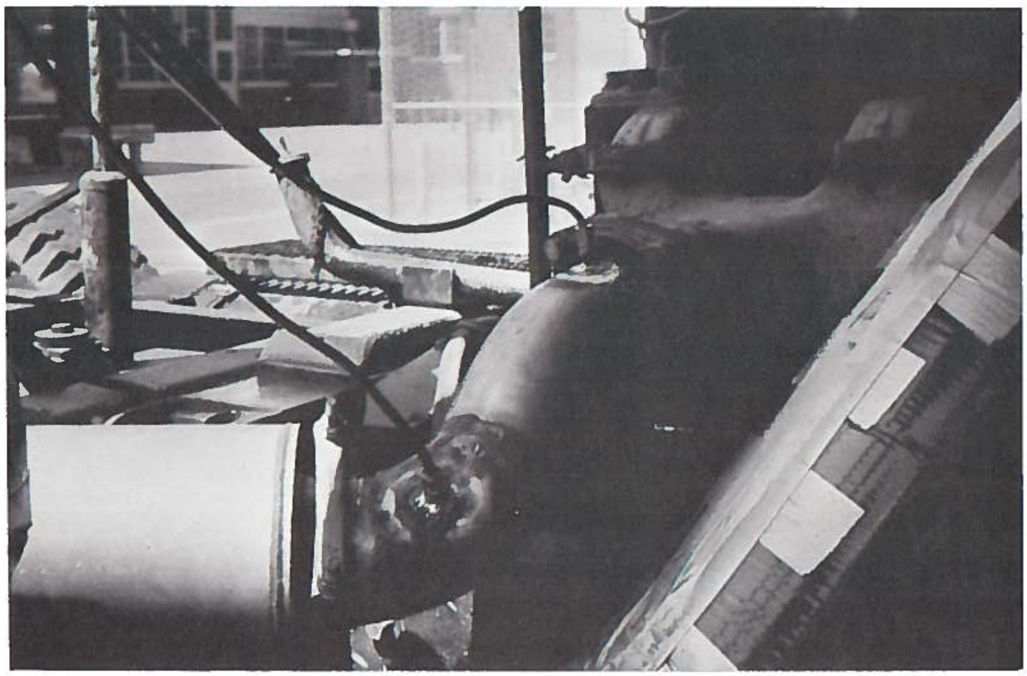


FIGURE 5.8 DONALDSON RESONATOR INSTALLED.

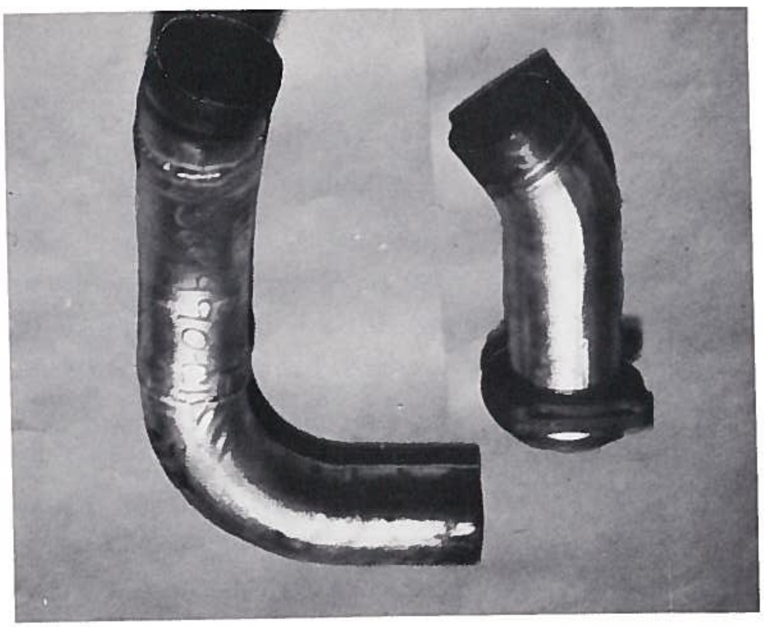


FIGURE 5.9 DOUBLE WALL PIPE.

by Northern Tube consisted of simultaneously rolling and welding two pieces of sheetmetal, each .042 in. (1.067mm) thick, that resulted in high pressure contact between the two walls. The sample was evaluated in conjunction with Donaldson muffler 549483-Cl. The double wall pipe replaced the original exhaust pipe from manifold to the muffler inlet. The data from SAE drive-by test indicated that in the total truck environment of COF4070A, the double wall pipe was ineffective in reducing the exhaust noise by sufficiently dampening the shell vibrations.

Northern Tube Company representatives visited IH again and reviewed the test procedure and the data. Although they were fully convinced, they found the results contrary to their previous experience. During the discussion it was established that their previous experience involved a longer pipe section between the exhaust manifold and muffler. Also, the larger the pipe section, the greater the acoustical energy emitted. From this standpoint, CO4070A notably has a smaller pipe section compared to similar model trucks by other manufacturers. This may, to a certain extent, explain the apparent disparity in results.

5.4.1.4 Riker Muffler

Riker Manufacturing Inc. supplied their recommended muffler 9XD405 for SVVTP system on the COF4070A for evaluation. Pertinent specifications are shown in Table 5.1. The SAE drive-by test results indicated a 3 dB(A) reduction in baseline exhaust noise level. This was not a wrapped muffler in contrast to the Donaldson muffler 549483-Cl.

5.4.1.5 Stemco Muffler

Stemco Manufacturing Company, Inc. provided their recommended muffler #9870 for single vertical system on

COF4070A. Stemco reportedly utilizes a series of resonators and cavity chambers designed to reduce low frequency noises created in the diesel engine exhaust systems. The muffler is constructed with heavy gauge aluminized steel for corrosion resistance. Again, in contrast with the Donaldson muffler 549483 Cl, it is not a wrapped muffler. The muffler evaluation indicated about 3.5 dB(A) reduction in the baseline exhaust noise level during SAE drive-by tests.

5.4.1.6 Cowl Spiral Silencer

Cowl Noise Abatement Products, Division of James B. Carter Ltd., Budd Company, was contacted for cooperation in the development work under the retrofit contract. The silencer design consists of a spiral passage of constant cross-sectional area, lined with stainless steel wool. The sound waves are reflected into the wool covered wall. The wool diffuses the sound waves and progressively attenuates the sound as exhaust gases pass through the multiple turns of the spiral.

Available in-house were Cowl's "S" series model silencer previously recommended to Engineering. Cowl's product number S40TR silencer for the SVVTP system, as shown in Figure 5.10, was evaluated on the COF4070A primary truck per SAE J366b standard procedure. Exhaust noise level was reduced by one dB(A). Exhaust backpressure was measured to be 1.2 in. Hg (30.5mm).

Later, the representatives from Cowl, James B. Carter Ltd., and Budd Companies reviewed the data on S-series silencers, and revised their recommendation to "XS" series model silencer. Since it was late in the program for COF4070A primary chassis, the recommended "XS" series model silencer was later evaluated on 2000D primary truck where only 2 dB(A) reduction was recorded in the baseline exhaust noise

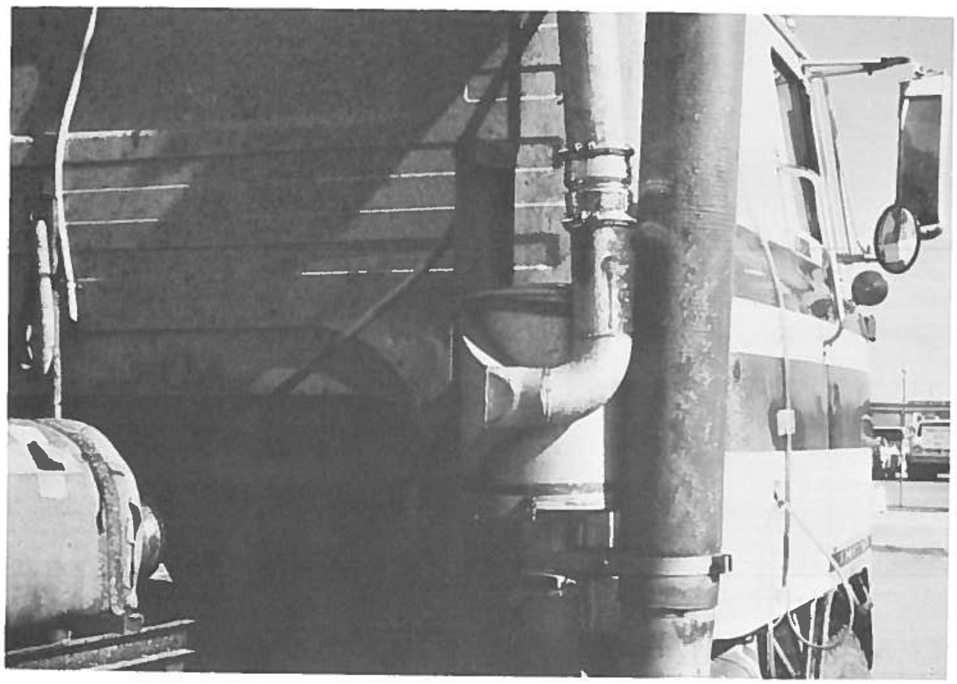


FIGURE 5.10 COWL SILENCER - MUFFLER INSTALLED.

level (See Chapter 6).

5.4.2 Cummins Engine Noise Suppression Kits

In section 5.3.3 on engine source identification of NHC-250 in the COF4070A primary truck, it was explained that the engine treatment was considered as partial source identification. Thus, Cummins' covers and panels were employed in treating the engine source noise.

The diesel engine noise, without fan, is mainly structure-borne noise which has two components: combustion noise and mechanical noise. Diesel engine noise is generated by internal exciting forces and is transmitted to the engine surface unsuppressed.

The diesel engine combustion forces distort or vibrate the oil pan, crankcase, intake and exhaust manifolds and attachments generating low frequency noise that is in the audible range. The structure responds to all harmonics, and hence, engine noise is generally described as that noise radiated from the structure.

The Cummins Engine Company, Inc. was contacted for their cooperation in this program. It was learned that their efforts to investigate the engine noise of the N-series engines has culminated in the development of noise suppression packages that effectively reduce the engine structure noise. The packages that are commercially available consisted of the following kits:

1. Oil pan panel kit Cummins #AR-11351;

2. Air intake manifold kit Cummins #AR-11356;

3. Engine Side panels and/or rocker housing kit Cummins #AR-11353.

The covers and panels and isolated intake manifold are shown in Figure 5.11. The block mounted engine side panels and the oil pan enclosure were made of sheetmetal lined with fiberglass. Upon installation, the fiberglass was sandwiched between the panels and engine block surface, with rubber grommets isolating the sheetmetal from the engine. The oil pan under tray (enclosure) construction was the same as that of the block panels, and it was made in two pieces for the ease of installation. These block sound panels as marketed by Cummins were designed for the basic N-series engines with openings and clearances for most common engine attachments. However, modifications in the form of cut and fit operation were necessary to accommodate individual vehicle fittings and accessories.

Isolated intake manifold was vibration isolated from cylinder head by using a soft mounting which increased the manifold width approximately 1/16 in. (1.5875mm) while the height remained same. The special rocker arm cover was also installed in the same manner. The isolated intake manifold and rocker cover are aluminum castings. The rocker cover reportedly has not been released for production.

It was suggested by Cummins to install these components in steps to evaluate their individual contribution in reducing the engine noise. Accordingly, the individual items were tested on the NHC-250 engine in the COF4070A primary truck. Installation of the left side engine block panels required removal of compressor, injection pump, water filter assembly, all fuel and oil lines and fittings, and other accessories. Figure 5.12 shows the modified left side panels installed before reinstalling the accessories. The right side panel was easy to install since the accessories were not in the way. The right side panel is shown installed in Figure 5.13. The oil pan enclosure installation, as shown in Figure 5.14, was forced into place with a jack and a wooden

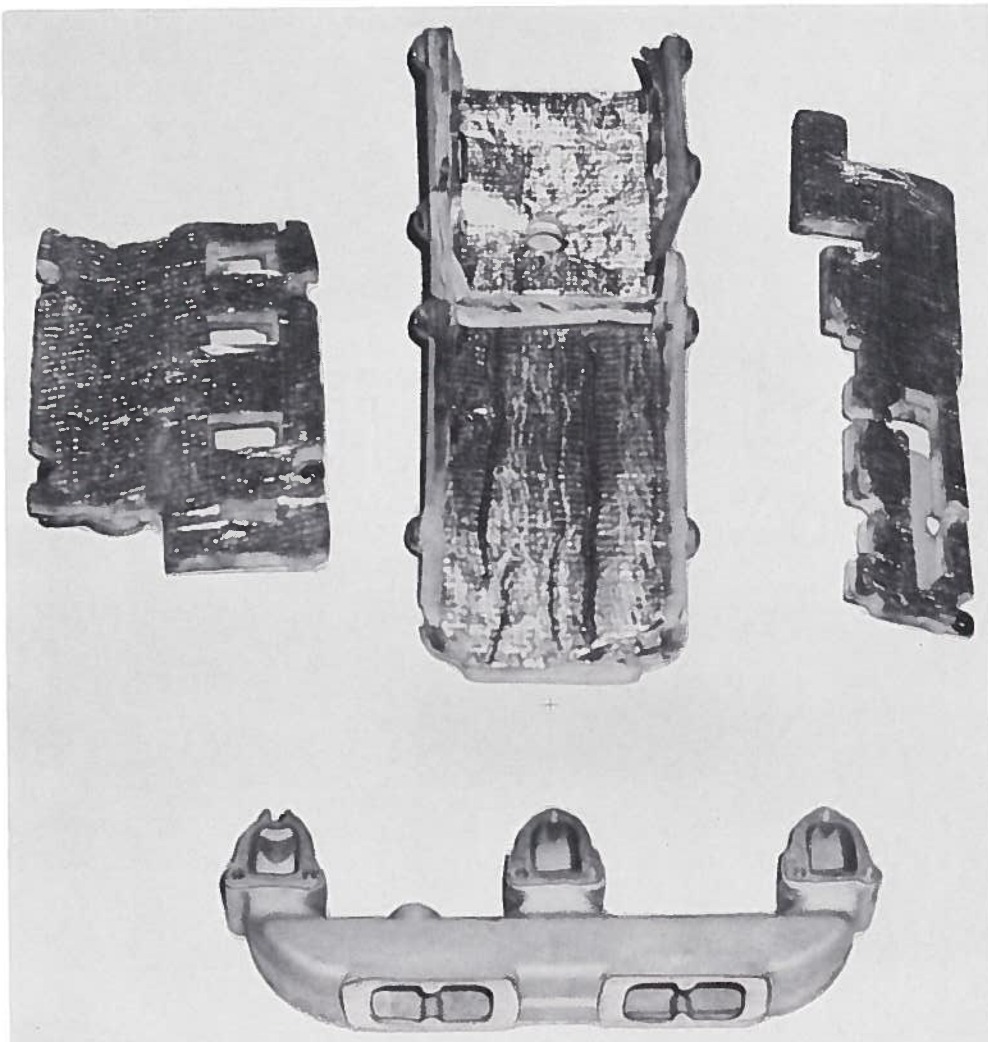


FIGURE 5.11 CUMMINS COVERS & PANELS.

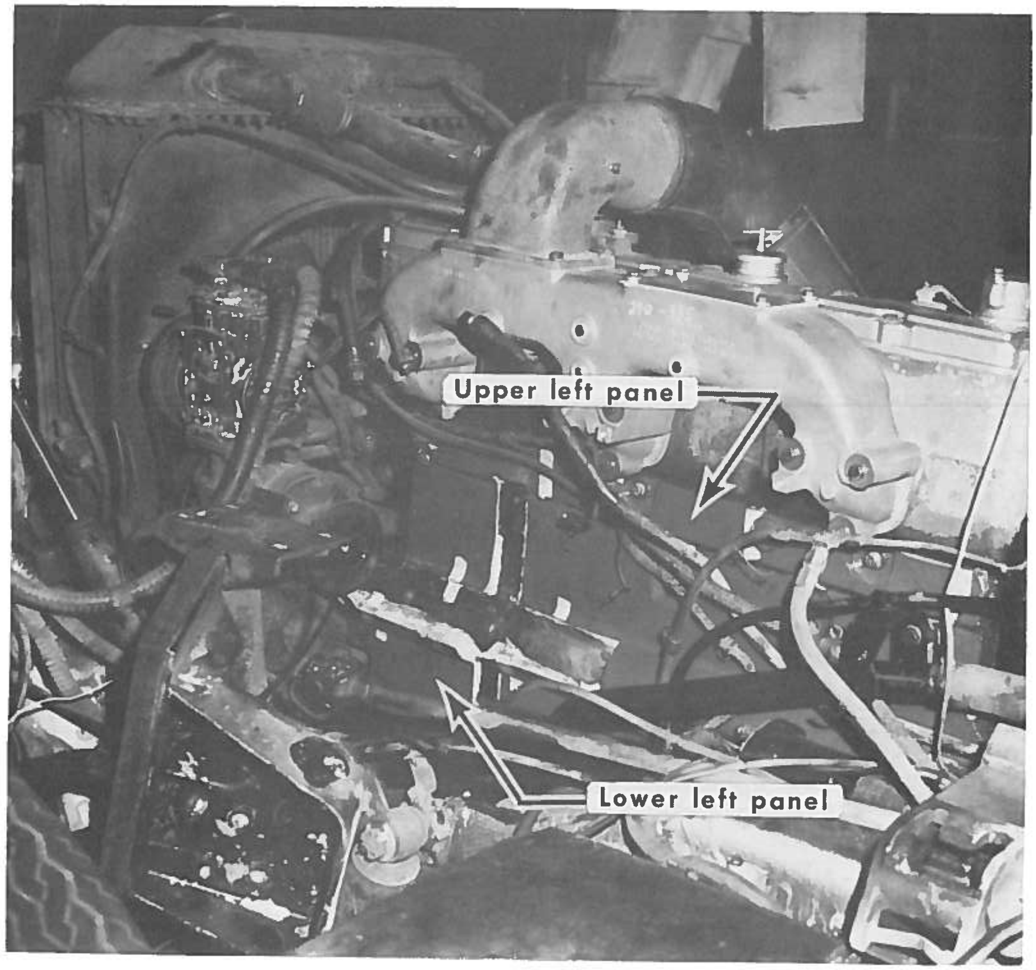


FIGURE 5.12 LEFT SIDE BLOCK PANELS INSTALLED.

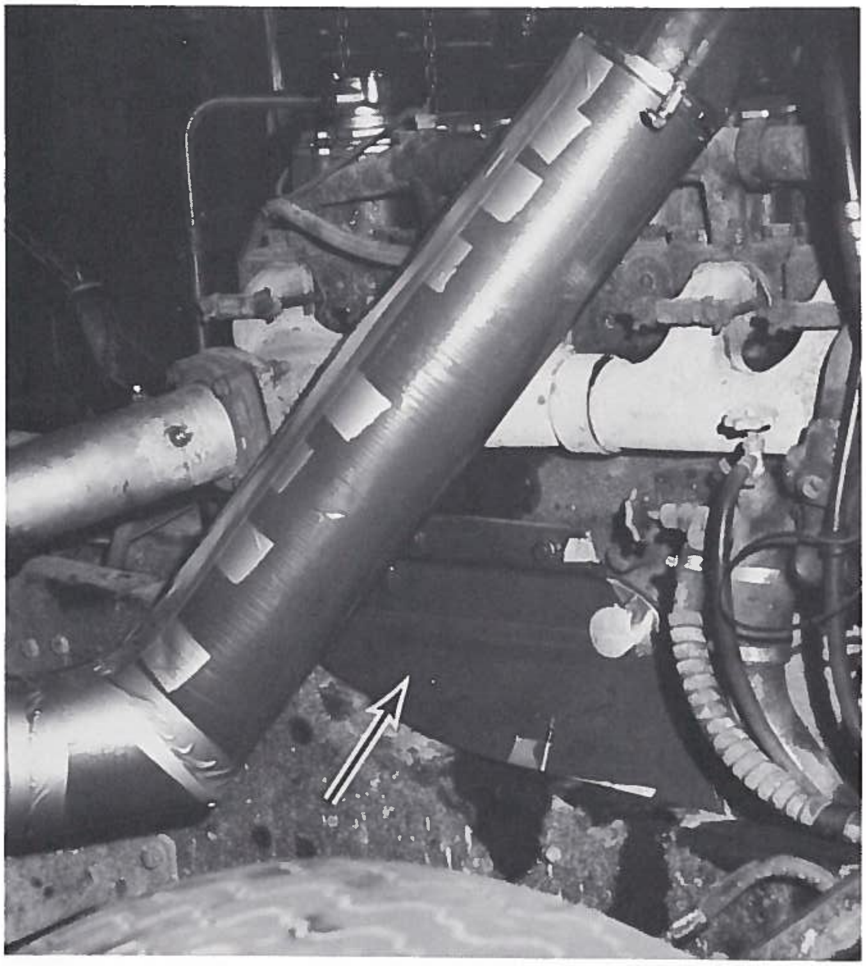


FIGURE 5.13 RIGHT SIDE BLOCK PANEL INSTALLED.

FIGURE 5.14 OIL PAN ENCLOSURE INSTALLED.

block to align the mounting holes. The installation was completed by utilizing the existing holes on the engine block for panels and oil pan mounting bolts for the enclosure.

The bar chart in Figure 5.15 displays the effectiveness of the engine noise suppressing hardware tested individually and in combination. It is evident from this chart that the oil pan cover first and then the engine block sound panels was most effective, whereas the combined effect of the isolated intake manifold and rocker cover was insignificant.

The Cummins N-series engines utilize cast aluminum oil pans that are rigidly mounted to the engine. An oil pan enclosure made of high density barrier material lined with an absorbent material effectively reduced the engine noise level by 2.7 dB(A).

5.4.3 Fan and Cooling System

The criteria in cooling system noise treatment was established to be maintaining equivalent cooling ability, ease of installation in the field, and cost. Judging from these criteria, the order of priorities was formed for developing cooling system noise modifications. First of all, the radiator change was ruled out in view of the many complexities involved. Then the following plan of action was established:

1. Optimize (production) fan location;

2. Seal the existing shroud to radiator joint;

3. Evaluate commercially available fans with the same diameter as that of the production fan;

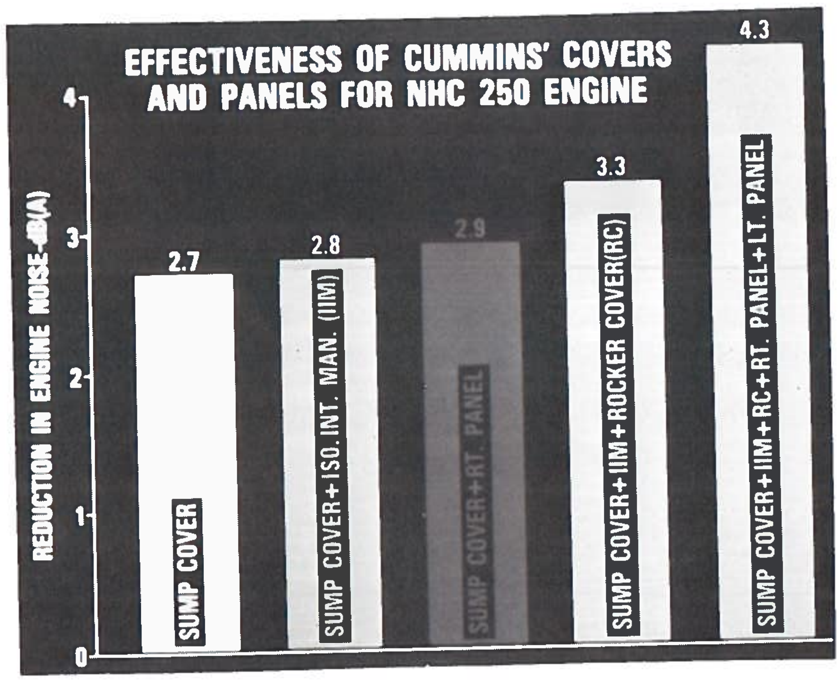


FIGURE 5.15 EFFECTIVENESS OF CUMMINS NOISE SUPPRESSING KITS.

4. Make shroud changes;

5. Use fan clutches.

The course of action in treating the cooling system noise was further guided by the results of the on-going Quiet Truck program at IH. The results of this program showed that it was sufficiently satisfactory to make air flow measurements to estimate the cooling effects, and to run SAE drive-by tests to determine the noise reduction potential of a particular modification under evaluation. Air flow was measured by mounting the flow duct, air tight, ahead of the radiator as shown in Figure 5.16. The air flow duct and measurement procedures are described in Appendix J.

5.4.3.1 Fan Spacing

The fan noise as produced is essentially due to turbulent flow and vortex shedding at the trailing edges of the fan blades and by aerodynamic interactions between fan blades and stationary obstructions such as fan belts, pulleys, engine protrusions, etc. Therefore, fan-to-shroud, fan-to-radiator core and fan-to-engine relationships have a direct bearing on the cooling fan noise. Although these important factors were fully recognized, no attempts were made to separate the individual effects, as that would have required extremely time consuming and intricate testing, hence, beyond the scope of this contract. However, optimization of fan location in the space available for most effective utilization of the original hardware was in keeping with the aforementioned factors.

The original fan spacings in primary model COF4070A w/NHC-250 engine, are given in Table 5.3. The shroud had

FIGURE 5.16 AIR FLOW MEASUREMENT.

a contoured shape with 1.0 in. (25.4mm) nominal tip clearance, and the baseline fan installation had 130% of the fan projected width of 2.4 in. (60mm) covered by the shroud. (The rear edge of the fan blades even with the rear edge of the shroud opening is defined as 100% fan coverage.) This is referred to as 130% fan coverage. In this condition, the baseline fan spacer was 2.85 in. (72mm) thick. Thickness of the spacer was varied to 3.5 in. (89mm), for about 160% fan coverage and 4.00 in. (102mm), for about 180% fan coverage.

TABLE 5.3 PRODUCTION FAN SPACING

Spacer Thickness in./mm	Fan-Core* in./mm	Fan-RR** in./mm	% Fan Coverage	Reduction in Noise Level dB(A)	Air Flow
2.85/72	2.95/75	1.65/42	130	Ref	Ref
3.5/89	2.3/58	1.5/38	160	2	No Change
4.0/102	1.8/46	1.00/25	180	0	No Change

* Leading edge to rear surface of radiator core.

** Trailing edge to nearest obstruction.

It can be seen from the results shown in Table 5.3 that the fan location was optimized with 3.5 in. (89mm) thick spacer where the fan noise level was reduced about 2 dB(A) without adversely affecting the air flow.

5.4.3.2 Sealing Shroud to Radiator Joint

In the production setup, the shroud was mounted to the radiator and was checked for openings between the shroud and radiator that would allow much air to escape. Except for narrow openings around the corners, the sides of the shroud were found to be flat tight against the radiator. These openings were sealed with silicone tape and the air flow measurement was made using a 3.5 in. (89mm) spacer. A gain of 9.5% in air flow was registered over the baseline measurement, however, without any favorable results from a noise standpoint.

5.4.3.3 Commerically Available Fans

Original equipment manufacturers for truck fans were contacted for their recommendations of best fans with regard to noise that would provide a cooling equivalent to the baseline fan. Since the cooling fan in COF4070A primary truck was mounted to the water pump shaft, it precluded fan drive ratio changes. Hence, they were requested to recommend fans designed to operate at same speeds as the baseline fan. Responses were received from Brookside, Flex-a-lite, and Schwitzer companies, and fans were procured and tested. The results in terms of air flow comparison and corresponding noise levels are shown in Table 5.4.

The fan provided by Brookside was a twisted blade fan with 1.5 in. (38mm) projected width at the tip which effectively reduced the fan noise level but failed to meet the cooling requirements. The Flex-a-lite fan had plastic blades and plastic center section and its evaluation revealed a 30% reduction in cooling without any measurable difference in the fan noise level. Schwitzer Company did not have an appropriate fan to offer for the COF4070A with NHC-250 engine. It may be noted that sealing the shroud with the Brookside fan did not offset the air flow lost by changing fans. The Brookside and Flex-a-lite fans are shown in Figures 5.17, 18, respectively.

TABLE 5.4 - COMMERCIALLY AVAILABLE FANS EVALUATED IN COF4070A

FAN	SPACER THICKNESS IN/mm	FAN-CORE IN/mm	% COVERAGE	FAN NOISE LEVEL	AIR FLOW COMP.	REMARKS
362907-C1(PROD)	2.85/72 (PROD)	3.20/81	130	80	REF.	
362907-C1(PROD)	3.50/89	2.56/65	160	78	No Loss	
362907-C1(PROD)	4.00/102	2.08/53	180	80	No Loss	
X-3618(BROOKSIDE)	2.85/72	3.65/93	90	78	22% Loss	
X-3618(BROOKSIDE)	3.00/76	3.50/89	100	78	21% Loss	
X-3618(BROOKSIDE)	4.00/102	2.56/65	160	75	18% Loss	
1522(FLEXALITE)	2.85/72	----	---	79.5	31% Loss	
362907-C1	2.85/72	3.2/81	75	80	7% Gain	Sealed Shroud
362907-C1	3.50/89	2.56/65	100	78	9% Gain	Sealed Shroud
X-3618(BROOKSIDE)	4.00/102	2.56/65	160	74	16% Loss	Sealed Shroud

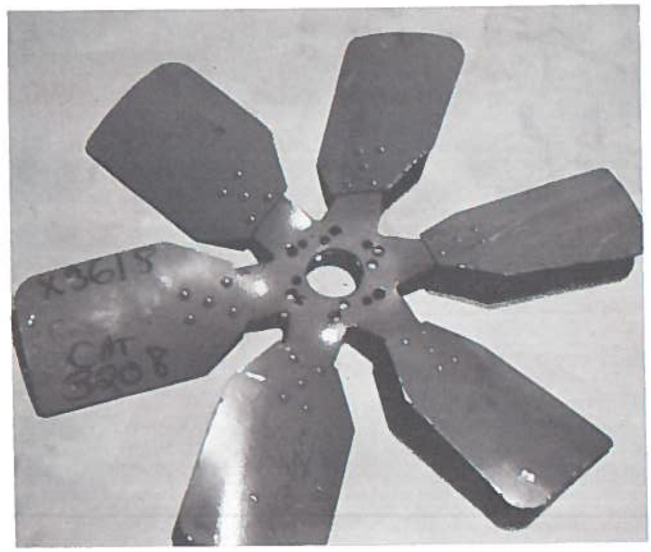


FIGURE 5.17 BROOKSIDE FAN.

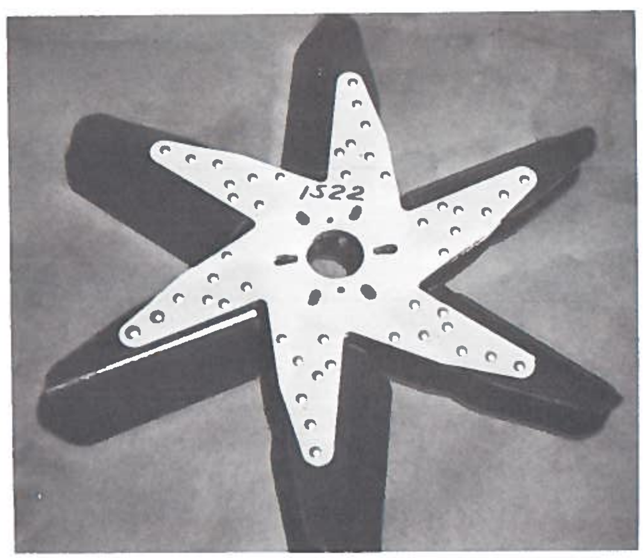


FIGURE 5.18 FLEX-A-LITE FAN.

5.4.3.4 Shroud Changes

As mentioned previously, the original shroud had a contoured lip which (from the results of Quiet Truck Program at IH) is considered superior to other shroud opening configurations. However, a large radial tip clearance of 1.0 in. (25.4mm) nominal is found to allow excessive recirculation around the tips of the fan. Therefore, a square edge type shroud, shown in Fig. 5.19, was evaluated to determine its effect while maintaining a 1.00 in. (25.4mm) tip clearance using the original fan. The air flow measurement indicated 2% reduction compared to baseline measurement, and the SAE drive-by test showed a 4 dB(A) increase in the fan noise level. Hence, from the noise standpoint, the original contoured shroud is superior to the box type shroud with nominal 1.00 in. (25.4mm) fan tip clearance.

5.4.3.5 Fan Clutches

The Cummins NHC-250 engine in this primary truck was a pre-1970 version that had the cooling fan mounted to the water pump shaft. This fact did not permit a change in the fan ratio. Further, the only fan clutch compatible with water pump mounted fan is the viscous type. Therefore, the possibility of using a viscous fan drive was investigated. Rockford Clutch, Division of Borg Warner and Schwitzer Company were approached for their input in this matter. It was reported that there was nothing currently available that would provide a viscous fan drive. Although research work is progressing, nothing was firmed up that would properly meet the requirements under the contract.

5.4.4 Turbocharger Kit Evaluation

It was noted in Section 5.4.2 that the diesel engine combustion forces caused the engine block to vibrate. The smoother combustion process, due to turbo charging,

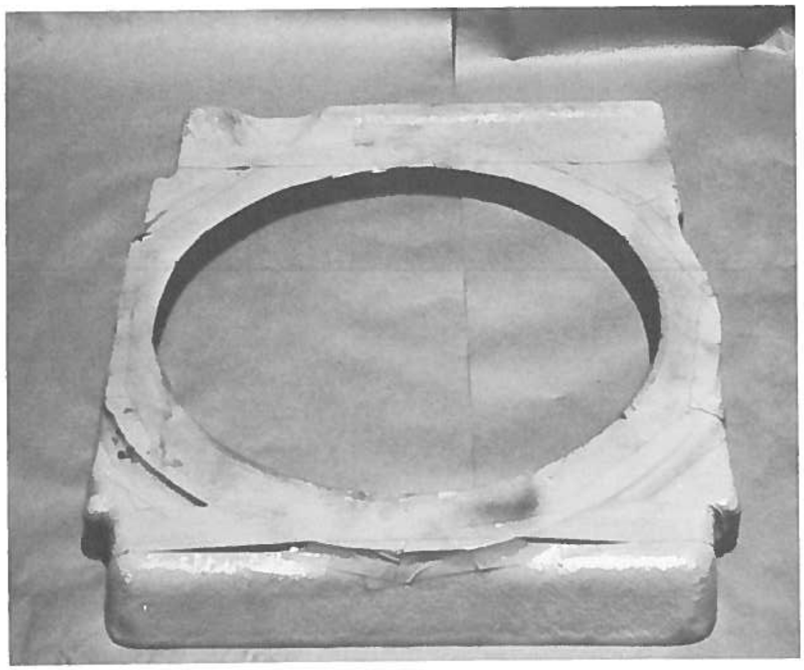


FIGURE 5.19 BOX TYPE SHROUD.

lowers the loading of the piston and related parts. In a simulated mass-spring system for an engine, the combustion forces are input to the system and vibration and resulting noise is the output. The turbocharger (installation) reduces the peak input forces by smoothing the combustion process.

Cummins have developed add-on, after market turbocharger kits with special components as required for most popular truck makes and models for installation on their naturally aspirated engines for the advantages listed below:

1. Reduction in exhaust smoke;

2. Decrease in the rate of fuel consumption;

3. Compensation to maintain essentially same power output up to 12,000 ft. (3660M) altitude;

4. And, reduction in engine exhaust noise from the dampening effect of turbocharging.

However, horsepower uprating was not permissible due to limitations concerning compression ratio, timing and Federal Regulations.

An appropriate turbo charger conversion kit #AR-10188 was procured from Cummins for installation and evaluation on NHC-250 in COF4070A primary truck. The components of the kit are shown in Figure 5.20. Due to high kit and installation cost, the evaluation of turbo kit was carried out with all other baseline hardware such as exhaust muffler, intake air cleaner and fan, etc. Drive-by noise level per SAE J366b drive-by test with just turbo kit installed on the baseline vehicle indicated a 3 dB(A) reduction from the baseline measurement of total truck exterior noise level of 87 dB(A). Interior noise level per BMCS test

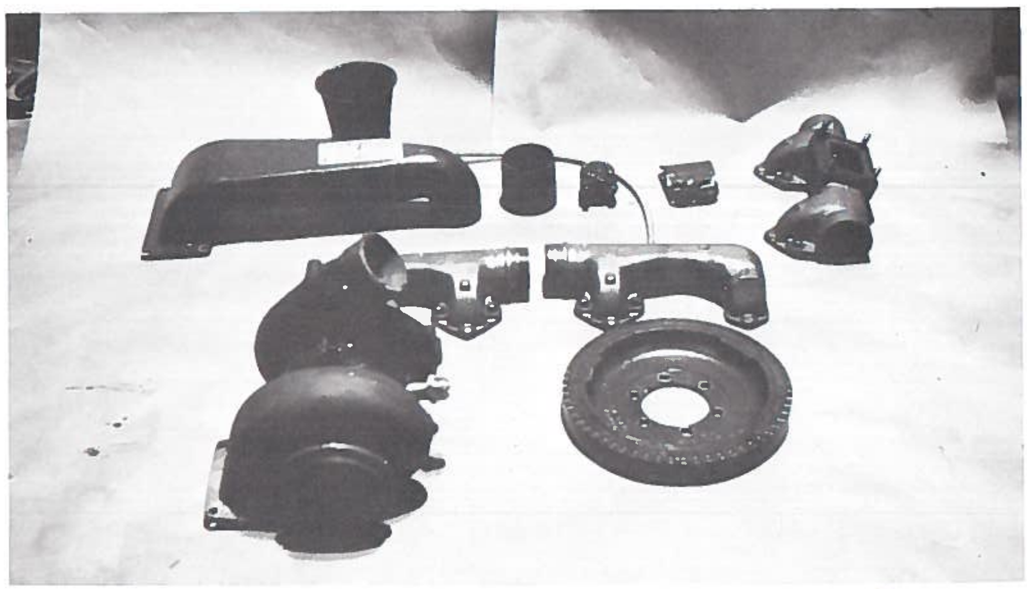


FIGURE 5.20 TURBOCHARGER KIT.

procedure remained unchanged.

5.5 FINAL KIT EVALUATION

Based upon the noise rating of the commercially available components discussed in the preceding sections, the effective noise reducing components were selected. The selection was contingent upon cost to the customer and ease of installation in the field, while accomplishing the arbitrary goal of 83.0 dB(A) for primary truck noise level.

Thus, for COF4070A with NHC-250 engine primary truck, the selected components are as shown in Table 5.5 below.

TABLE 5.5 FINAL KIT COMPONENTS

NOISE SOURCE	COMPONENT DESCRIPTION	MANUFACTURERS'/IH PART NUMBER	EVALUATED NOISE RATING dB(A)
Exhaust	Muffler	WTM10-0066/549483-C1	78
Fan	Spacer, 3.5 in. (89mm) thickness	Add 391987-C1 to existing spacer	78
Engine	1. Block Sound Panels	Cummins AR-11353)	77
	2. Oil Pan Enclosure	Cummins AR-11351)	

The theoretical prediction of 83 dB(A) for total truck noise level was established by acoustically adding the evaluated rating of the individual optimized components as shown in Figure 5.21.

5.5.1 Exterior Noise

The selected noise reducing components were collectively installed on the truck and SAE drive-by test was conducted. The total truck exterior noise level was found to range between 82 and 83 dB(A), matching fairly close to the theoretical prediction. Baseline versus final source and total truck noise levels are presented in the bar chart, Figure 5.21. It shows reductions obtained in the source noise levels and total truck noise level. Noise level versus truck position and noise level versus frequency plots for baseline and final retrofitted trucks are given in figures 5.22 and 23. The frequency plot shows the spectrum at the peak truck noise level. These components were considered to be final noise reduction modifications, and final data acquisition was completed by running all the tests listed in Section 3.

As stated in Section 3.2, it was required by the contract to record constant speed drive-by noise levels at engine revolution rates representing 80, 90 and 100 percent of maximum governed value. The test procedure is similar to that covered in the SAE J366b Standard Practice which is given in Appendix B. The constant speed drive-by tests were made for the baseline and final modified truck. The sound level versus truck position was plotted along with SAE J366b drive-by noise levels to analyze the data trend. The plot for baseline truck is shown in Figure 5.24. It indicated that the constant speed drive-by noise level with 100 percent governed engine speed is lower in the end zone but higher at the beginning of the measurement zone compared to the regular drive-by noise level. That is, the sound levels versus truck position plot tends to become flatter, and, as can be seen from the plot, distinctly so with the lowered governed engine speed. Hence, the fan noise decreases at a slower rate compared to the engine related noises and exhaust noise.

5.5.2 Interior Noise

Truck interior noise level was measured per BMCS interior noise regulations with the selected components installed

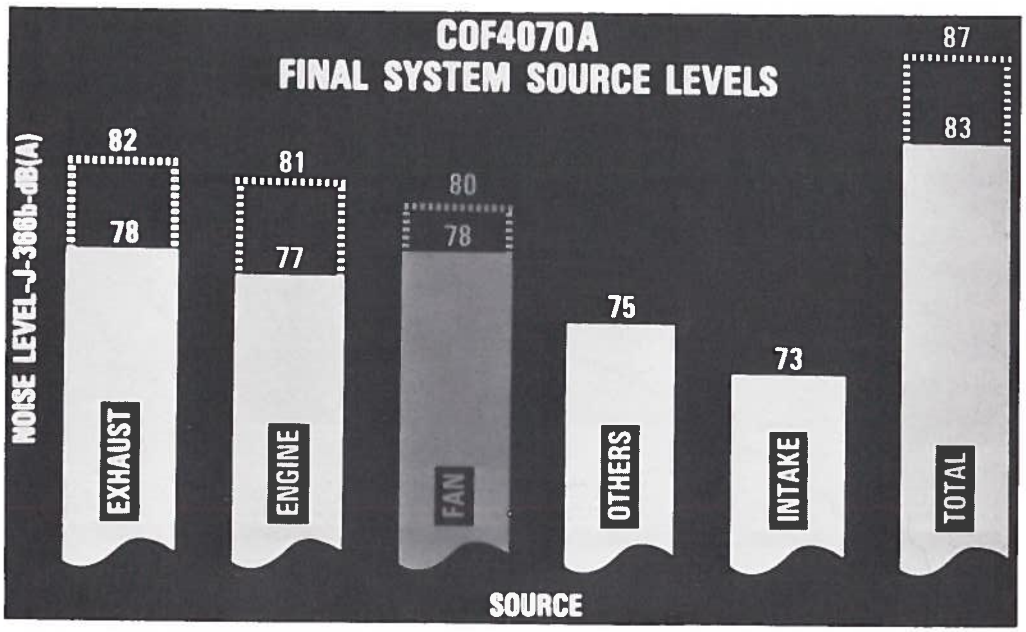


FIGURE 5.21 FINAL SOURCE NOISE LEVELS.

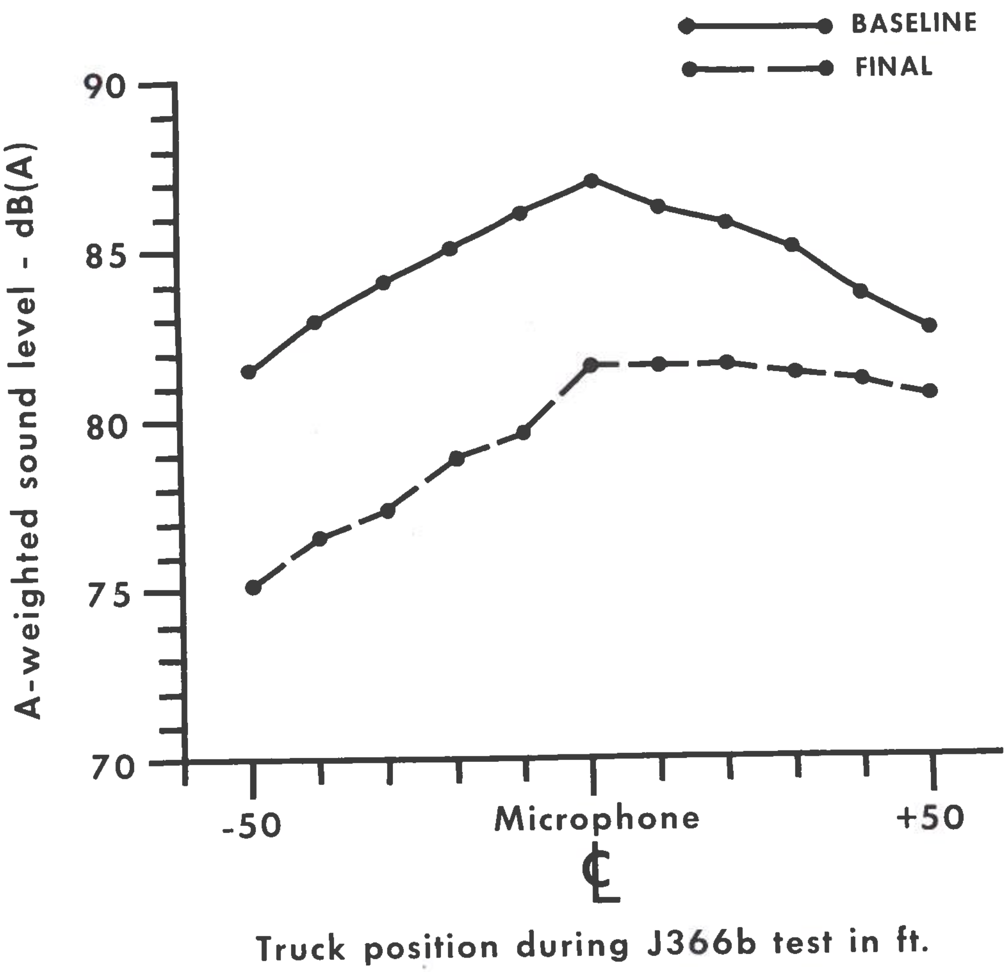


FIGURE 5.22 BASELINE & FINAL NOISE LEVELS VS. TRUCK POSITION.

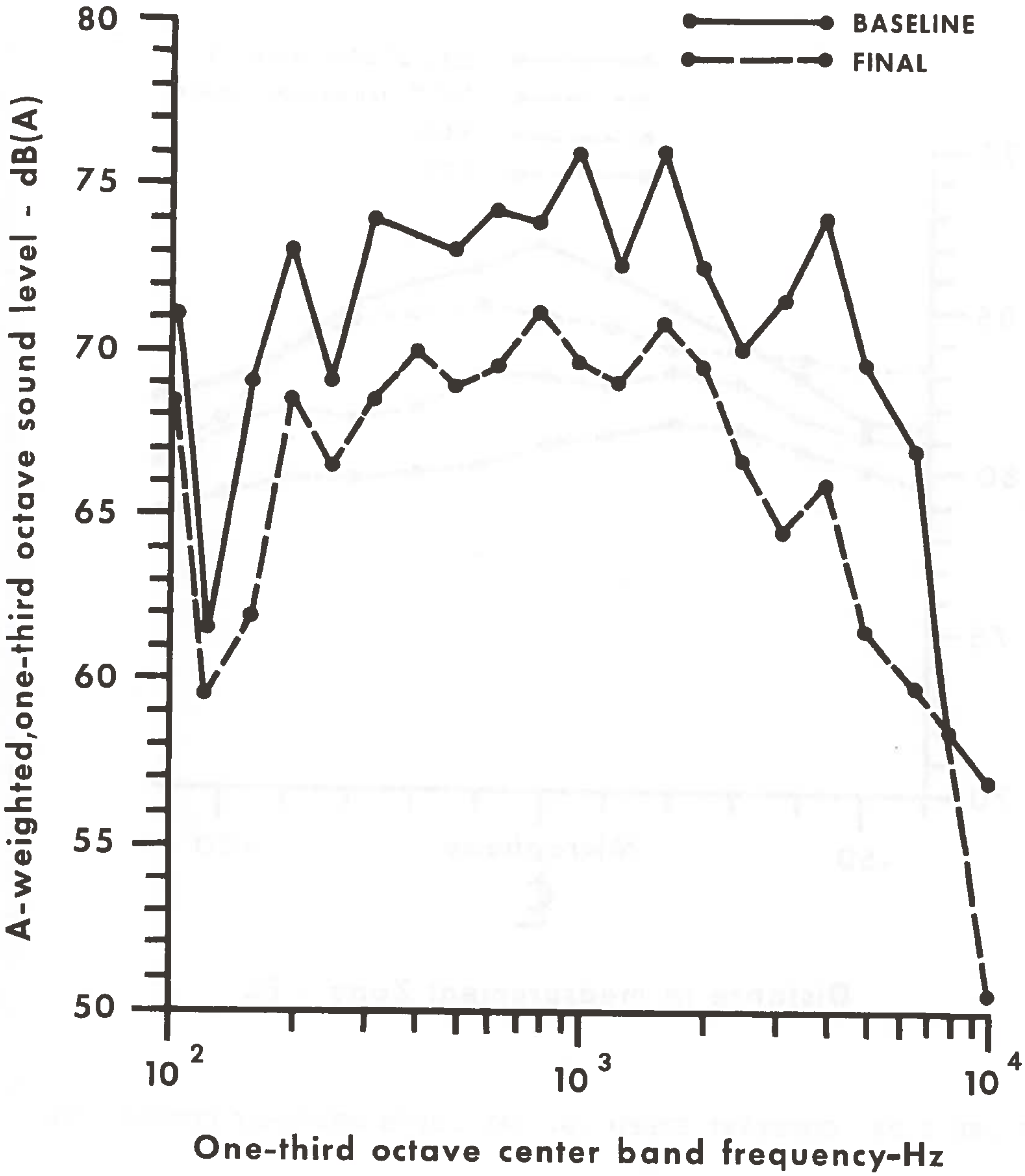


FIGURE 5.23 BASELINE & FINAL NOISE LEVELS VS. FREQUENCY.

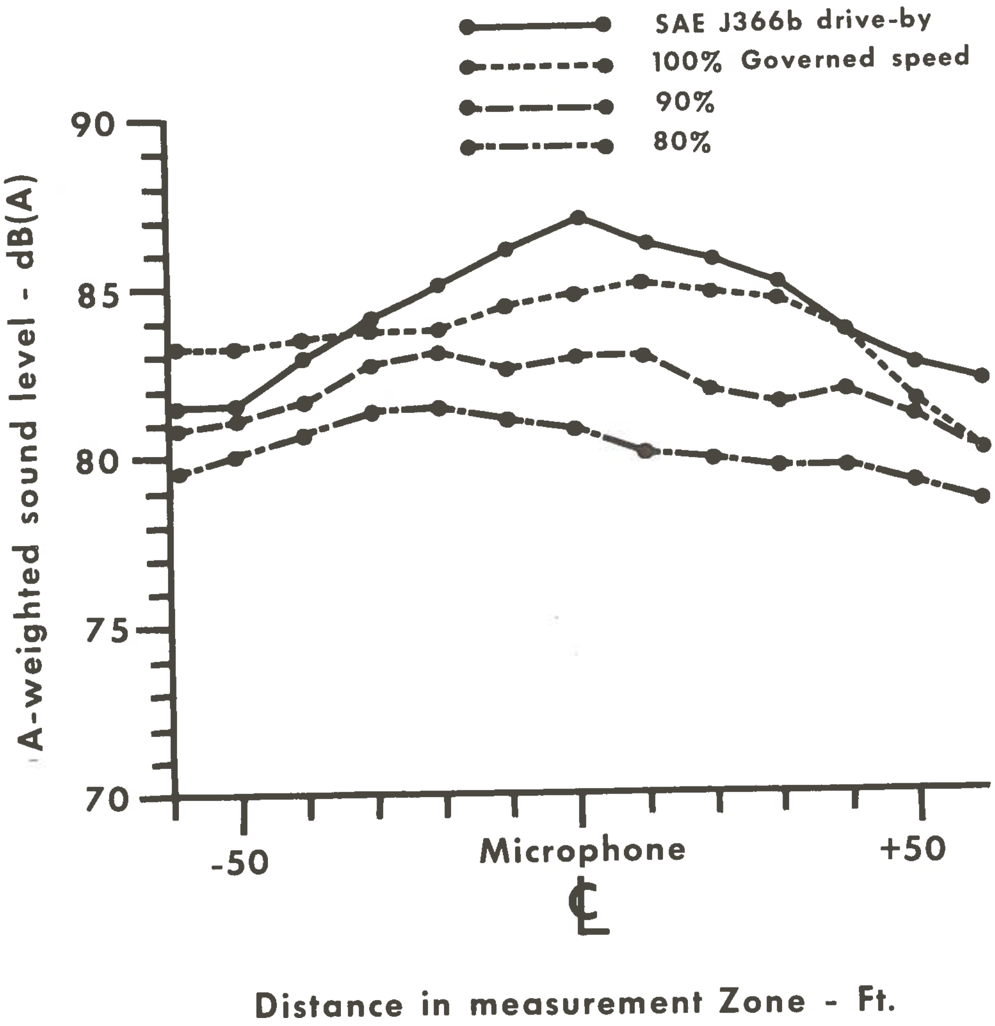


FIGURE 5.24 CONSTANT SPEED VS. SAE J366B DRIVE-BY COMPARISON.

collectively and was found to be 85 dB(A), a 2 dB(A) reduction from the baseline measurement. This interior noise reduction was recorded as an added benefit of the exterior treatment. Again, additional interior noise measurements were made as listed in Section 3. The bar chart in Figure 5.25 shows baseline and final interior noise levels.

5.5.3 Design Feasibility

For purposes of evaluating individual noise abatement components on the primary truck, experimental parts were applied in the most expedient manner. Therefore, in the design of the final retrofit kits, it was necessary to design more permanent bracketry and other mountings as required from the feasibility and durability standpoint.

The installation of the selected exhaust muffler required the redesign of the muffler clamp, shield and angle support bracket. Redesign of these parts was necessary due to a change in body diameter from 9.00 in (229mm) of the baseline muffler to 10.00 in. (254mm). Also, the selected muffler was about 20 lb. (9kg) heavier than the baseline muffler.

The cooling system noise treatment involved optimization of fan location requiring spacer thickness change from the baseline 2.85 in. (72mm) to the final 3.5 in. (89mm). From the IH parts retrieval system, it was determined that a spacer of 3.5 in. (89mm) thickness did not exist, and, as such, required tooling a spacer. However, a spacer of 3/4 in. (19mm) thickness was available in the system which then added to the baseline spacer of 2.85 in. (72mm) thickness provided a total thickness of 3.6 in. (91mm), and was considered adequate. This arrangement proved more cost effective than a new spacer of 3.5 in. (89mm) thickness.

The installation of the block sound panels and oil

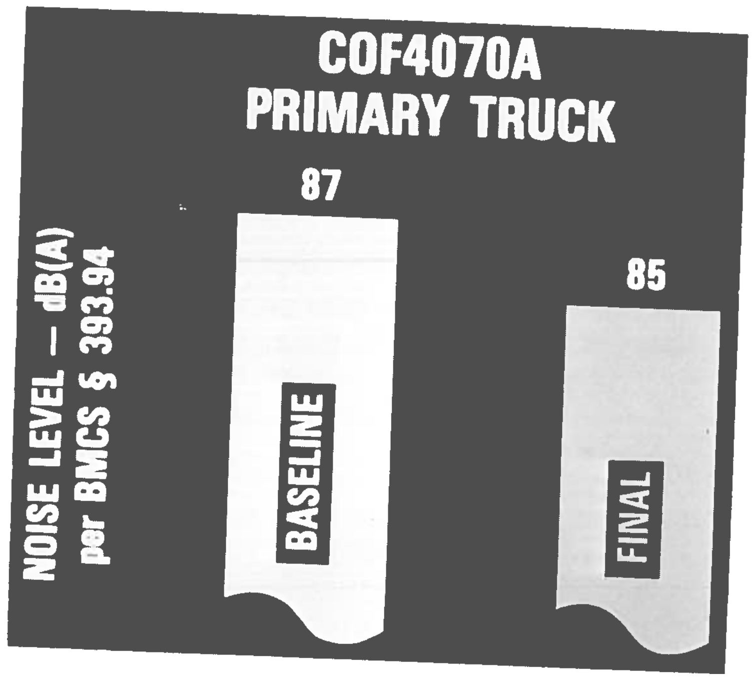


FIGURE 5.25 INTERIOR NOISE LEVELS.

pan enclosure required many modifications. The basic panels and covers are designed, manufactured and marketed by Cummins for all N-series engines including naturally aspirated and turbocharged. However, modifications are necessary in the covers and panels due to variations in the mounting location of the engine accessories.

A service bulletin, distributed separately to owner-operators, and, to be included in Part Two of this report, gives figures, illustrations and instructions for installation of these noise reducing modifications. It deals with both primary and secondary series vehicles.

5.6 APPLICABILITY TO SECONDARY TRUCKS

As described in Section 4, spreadability of results obtained on the COF4070A with the NHC-250 engine primary truck to the secondary trucks was a major consideration of this program. Applicability of the selected noise reducing modifications to the secondary trucks was, therefore, investigated from two aspects:

1. Noise reducibility; and

2. Installation feasibility.

Engineering specifications and service parts catalogs were used for an initial feasibility study.

5.6.1 Applicability of Exhaust Modification

Application of the selected exhaust muffler 549483-C1 was found feasible on the CO4070A with NH-230 and with 6-71N engines since a single vertical muffler, vertical tailpipe (SVVTP) was the only exhaust system offered in production (4.00 in. (102mm) inlet-outlet). The same muffler shield, angle and support brackets, designed for the primary truck were usable. However, CO4070A with turbocharged engines (NTC-290, 335 and 350), had an SVVTP system with a 5.00 in. (127mm) inlet-outlet. Hence, the above selected muffler could not be used in this case. Thus, another commercially available muffler 467355-C1 (Donaldson No. MFM09-0249) with 5.00 in. (127mm) inlet-outlet system was selected based upon Donaldson's recommendation. Installation effects were found to be minimal since body diameter of this muffler is the same as that of the baseline muffler, IH no. 753980-C91 (Donaldson No. MUM09-0074). But the overall length is 10 in. (254mm) longer and required additional clamps to rigidly fasten the intake stack and muffler.

5.6.2 Applicability of Fan Modification

Since an identical cooling system is offered in CO4070A with the NHC-250 and NH-230 engines, the same modification of added spacer, 3/4 in. (19mm) thick, to optimize the fan location was applicable. The secondary truck, CO4070A with 6-71N, had a box type shroud with a 24.0 in. (610mm) diameter fan that was not 100% covered by the shroud. Further, a number of different core thicknesses were offered in production that changed the fan-to-core and fan-to-rear relationships accordingly. Dimensional analysis revealed that the fan-to-core distances with various core thicknesses ranged between 3-3/4 in. (83mm) and 2-7/8 in. (73mm). It was learned from the optimization effort on the primary chassis that a fan-to-core distance slightly over 2.0 in. (51mm) provided best results from the standpoint of noise reduction. Therefore, it was determined to replace the standard spacer of 1.00 in. (25.4mm) thickness by a spacer 411451-C2 of 2.45 in. (62mm) thickness for optimization of fan location. It was also discovered that 6-71N had a change in the fan mounting pilot bushing in 1970. The spacers for pre-70 version of 6-71N engines have been discontinued. Therefore, in order to be able to benefit from optimization it was found necessary to change pilot on pre-1970- 6-71N engine to post-1970 type and then install fan spacer #411451-C2.

The fan location in CO4070A with turbo charged engines was originally such that fan-to-core distance was considerably less than 2.00 in.. (51mm). Any optimization effort would have required an extensive redesign and evaluation. Therefore, it was beyond the scope of the contract, and consequently the fan source noise in CO4070A with turbo-charged engines remained untreated.

5.6.3 Applicability of Engine Modifications

Cummins covers and panels selected for the primary truck are designed to effectively reduce engine noise of all N-series engines. Therefore, the covers and panels are applicable to the secondary combinations of CO4070A with NH-230, NTC-290, 335 and 350 engines. But the engine treatment of any kind for the 6-71N engine in CO4070A is not commercially available.

It can be seen from the preceding paragraphs that the noise reducing modifications developed on the primary truck could be effectively applied to the secondary trucks.

6. DEVELOPMENT WORK ON 2000D

The same systematic steps of development work were followed in sequence on the 2000D, second primary truck, as for COF4070A (1st Primary Truck) described in Section 5. Since the same techniques and procedures were maintained, discussion in this chapter will be limited to those events that were uniquely different.

The exterior noise level of the as received vehicle per SAE pass-by test was 87 dB(A), and the interior noise level per BMCS regulation was 94 dB(A).

6.1 BASELINE TRUCK

Basic component description for 2000D is given in Table 6.1. The standard exhaust on this truck was a 4 in. (102mm) inlet-outlet system with a frame mounted single horizontal muffler, vertical tailpipe (SHVTP). The baseline truck is shown in Figure 6.1.

6.2 PRELIMINARY INSPECTION

From the as-received vehicle exterior noise measurement, an extraneous noise was detected. It appeared to be generating in the scavenger blower assembly which was removed and overhauled. But the problem remained uncured. Further, near field measurement was taken on linear scale and was frequency analyzed to define that this noise appeared in the 4000 Hz band only. Since it was a squealing noise, the peak was plotted and modulation frequency was calculated to be about 860 Hz. This frequency was close to the frequency of a point on the fan drive belt. Therefore, all new accessory

TABLE 6.1 - BASIC COMPONENT DESCRIPTION OF PRIMARY TRUCK 2000D

Make:	International Harvester
Cab:	Conventional - Tilting, Fiber-glass Front End
Wheelbase:	144 in. (3.66M)
GVWR:	35,000 lb. (15900kg)
Engine:	Detroit Diesel 6-71N With N-65 Injectors (238 HP)
Transmission:	Fuller RT-910 (10 Speed)
Exhaust System	Single 10.0 in. (254mm) Diameter Frame Mounted Horizontal Muffler, IH No. 256017-C91, 4.0 in. (102mm) In and Out, With Vertical Tailpipe (SHVTP)
Induction System:	Engine Mounted Air Cleaner, IH No. 273537-C91
Fan:	IH No. 433150-R91, 24.0 in. (610mm) Diameter, 6-Blades
Front Axle:	Rockwell FE-901, 12000 lb. (5400kg) Wide Tread
Brake System:	IH - Air
Clutch:	Spicer 14 in. (356mm)
Rear Axle:	IH RA-57, 23,000 lb. (10400kg) Single Reduction
Suspension:	IH Vari Rate 18500 lb. (8400kg)
Date Built:	November, 1969
Mileage:	412288 Miles (663512KM)

FIGURE 6.1 BASELINE TRUCK - 2000D.

belts were installed which affected the squealing noise. It was not as aggravating now. Besides, it was being attenuated on A scale and did not significantly effect the overall "A" weighted noise level. New baseline muffler and intake element were then installed to assure that it was a properly maintained truck for baseline noise measurement.

6.3 BASELINE NOISE LEVELS

The baseline exterior and interior noise levels of 2000D in a suitable state of condition were measured. The SAE J366b drive-by test was run to establish the exterior noise level at 87 dB(A). The interior noise level was measured in accordance with the Bureau of Motor Carrier Safety regulation to be 94 dB(A). Furthermore, all the baseline tests enumerated in Section 3 were also conducted for both exterior and interior truck noise.

6.4 SOURCE IDENTIFICATION

The source identification technique was applied in the manner described in Section 5.3 where engine source noise was only partially isolated with adequate engine treatment.

6.4.1 Exhaust

The exhaust source noise identification of 2000D (second) primary truck was performed in an identical fashion as of the COF4070A (first) primary truck in Section 5.3.1 by artificially silencing the exhaust as shown in Figure 6.2. The drive-by noise test was made according to the SAE J366b Standard Practice without fan. This noise level was acoustically subtracted from the baseline noise level without fan which provided an exhaust source noise level of 83 dB(A).

FIGURE 6.2 SUPER QUIET EXHAUST INSTALLED.

6.4.2 Intake

The production air intake system had an engine-mounted air cleaner on 2000D primary truck. Therefore, a remote mounted absorption type muffler was used for intake source noise elimination.

The absorption type muffler that was readily available was developed earlier by the IH Vehicle Dynamics Group. It was constructed with thick metallic outer shell of 9.0 in. x 9.0 in. (229 x 229mm^2) and 6.0 in. x 6.0 in. (152 x 152mm^2) inside dimension, 6 ft. (1.83M) long. It had a 1-1/2 in. (38mm) thick insulation with a perforated inner lining.

This silencer-muffler was installed behind the cab on the frame and connected to the intake opening with a long rubber hose as shown in Figure 6.3. A drive-by noise level without fan was obtained per SAE J366b Standard Practice. It was then acoustically subtracted from the truck noise level of exhaust reduced and fan removed which gave the estimated intake source noise level of 74 dB(A).

6.4.3 Engine

The Detroit Diesel model 6-71N65 engine in the 2000D primary truck is an inline, 6-cylinder, blower scavenged engine with a stamped sheet metal oil pan. The engine source noise level was determined as follows: The noise level estimated for "Others" sources was subtracted from the noise level obtained with artificially silenced exhaust and intake and fan removed which gave the engine source noise level of 81 dB(A).

Since the transmission was the same (Fuller RT-910)

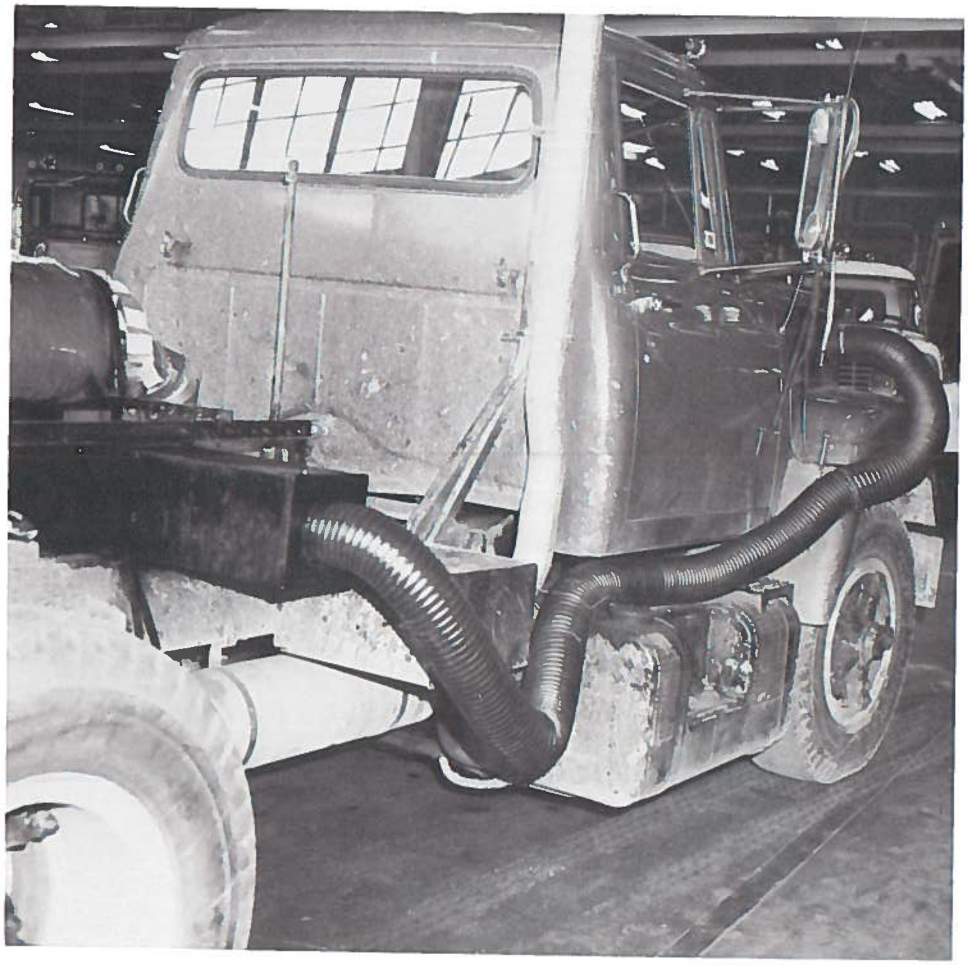


FIGURE 6.3 SUPER QUIET INTAKE INSTALLED.

in 2000D as that in the COF4070A, the noise level of "Others" sources was estimated in a similar manner by adding the coast-by noise level and transmission noise level.

Although engine source noise level was obtained without artificially silencing the engine, an adequate engine treatment was essential since the vehicle had to be reasonably silenced for the evaluation of the noise reducing components for other sources. Therefore, partial engine source noise suppression was accomplished by installing a simulated bellypan and engine enclosure using vinyl barrier material. The bellypan is discussed in detail in Section 6.5.4.

6.4.4 Cooling System

The cooling system source noise was identified by simply removing the fan and making the pass-by run. Therefore, the total truck noise levels with and without fan when other major sources were reasonably silenced, subtracting the latter from the former, provided a cooling system noise level of 82 dB(A).

6.4.5 Silenced Vehicle

With the artificially silenced intake and exhaust fan removed, and partially treated engine, the total truck noise level was 80 dB(A). To further quiet the truck for development work, additional efforts were employed to isolate the fuel tanks from the mounting straps as the tanks were vibrating at engine frequencies. This was accomplished by installing isolating straps between the fuel tanks and mounting straps. The SAE drive-by test showed the silenced vehicle exterior noise level to be 79 dB(A). Fuel tank isolation is discussed in detail in Section 6.5.3. The bar chart in Figure 6.4 shows the identified source noise levels and the total truck

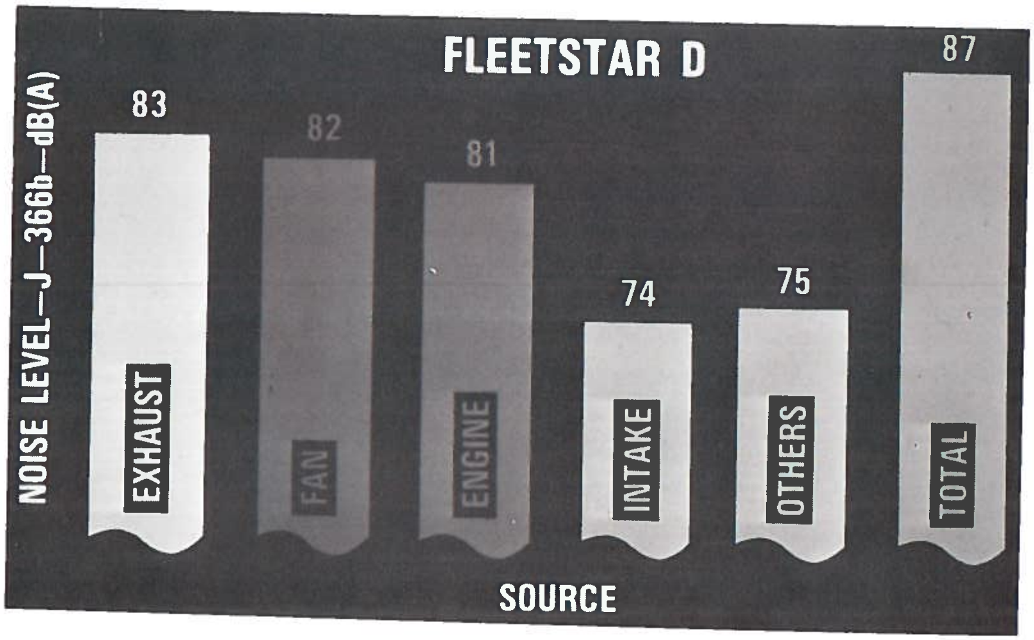


FIGURE 6.4 BASELINE SOURCE NOISE LEVELS.

noise level. (Data taken at peak total noise level.)

At the end of the development work, major noise sources were restored to their baseline condition, one at a time, and drive-by noise levels were recorded at each step to calculate the individual source noise levels. These figures confirmed the source noise levels described in the preceding sections.

The sound level versus truck position data for the baseline truck at its peak level and its major contributors at that point is plotted in Figure 6.5. The exhaust noise level peaked out at a point 10 ft. (3.08M) before the microphone whereas the engine noise remained high about 30 ft. (9.24M) past the microphone. The fan noise level increased continuously with the speed throughout the measurement zone and was maximum near the measurement zone.

Frequency spectrum is plotted in Figure 6.6 for the total as well as the individual major baseline noise sources. It depicts the frequency bands in which these major sources became predominant during the SAE drive-by test.

The vehicle at this point was ready to commence the evaluation of the noise reducing components recommended by the manufacturers.

6.5 COMPONENT EVALUATION

Various manufacturers of components pertinent to the Fleetstar D with 6-71N engine were contacted. The program was outlined and their participation within the scope of the contract was requested. Responses were very favorable. The recommendations received were carefully studied and components were procured for evaluation.

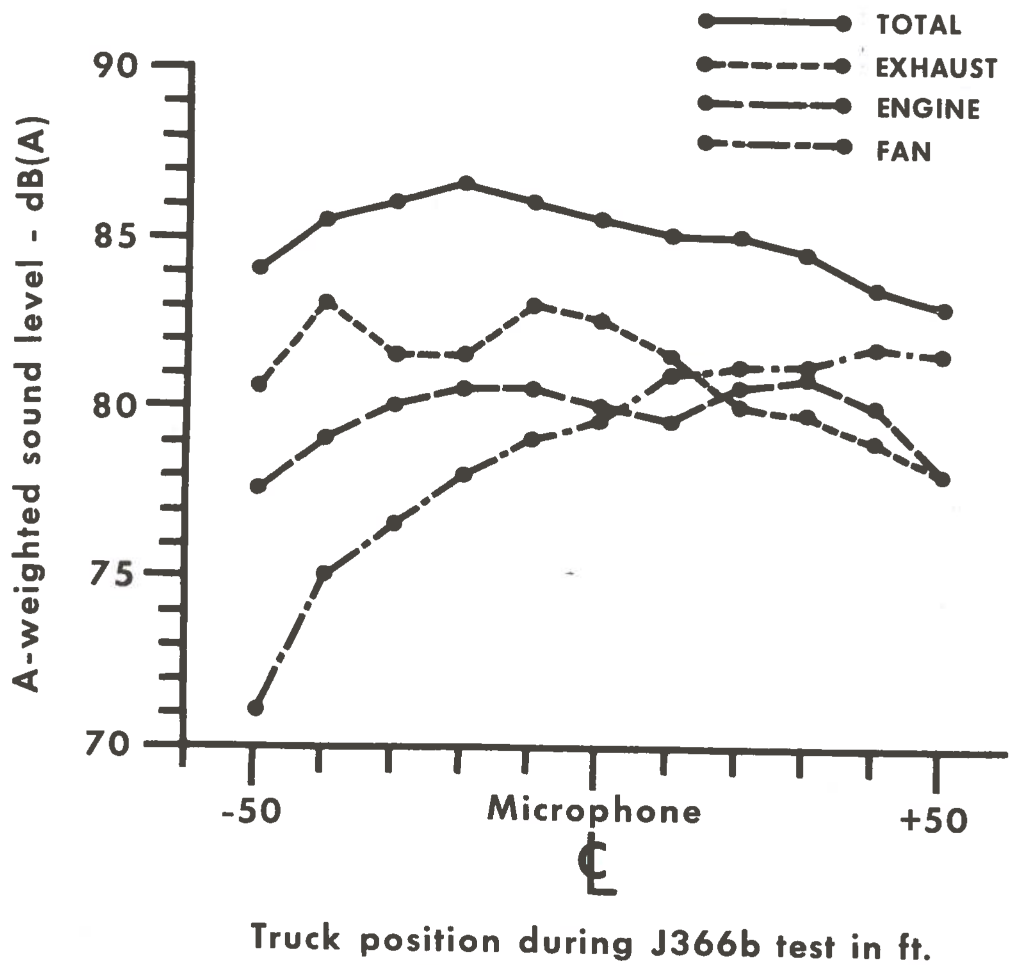


FIGURE 6.5 BASELINE SOURCE & TOTAL NOISE LEVELS VS. TRUCK POSITION.

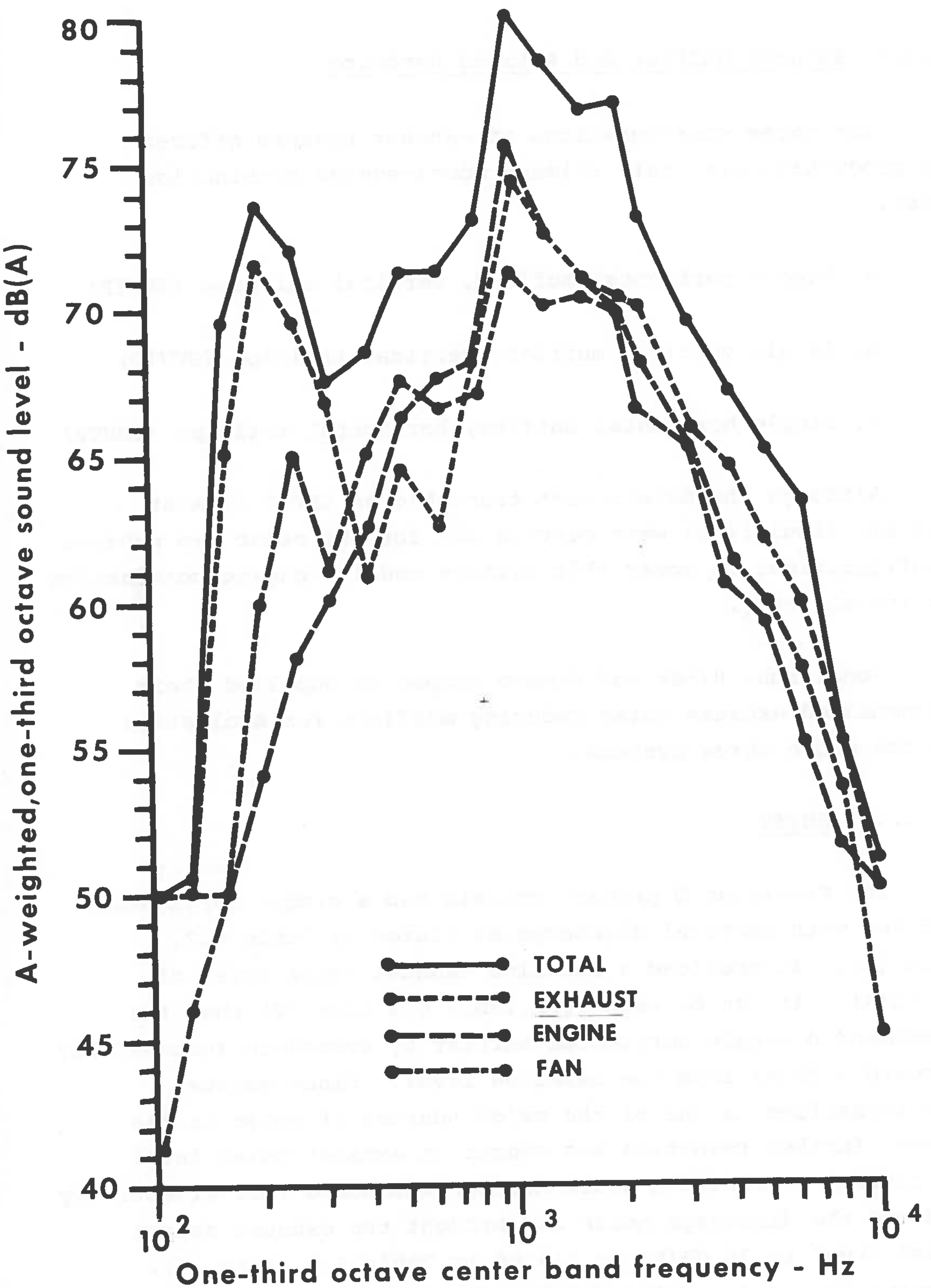


FIGURE 6.6 BASELINE SOURCE & TOTAL NOISE LEVELS VS. FREQUENCY.

6.5.1 Exhaust Muffler and Related Hardware

The three configurations of exhaust systems offered in production with this primary model-engine combination were:

a. Single horizontal muffler, vertical tailpipe (SHVTP)

b. Single vertical muffler, vertical tailpipe (SVVTP)

c. Single horizontal muffler, horizontal tailpipe (SHHTP)

Although the development truck had an SHVTP exhaust system, simulations were carried out for the other two exhaust configurations to cover this primary model - engine combination in its entirety.

Donaldson, Riker and Stemco companies supplied their recommended exhaust noise reducing mufflers for evaluation on the above three systems.

6.5.1.1 SHVTP

The Fleetstar D primary chassis had a single horizontal muffler with vertical discharge as listed in Table 6.2, item (1). It provided a baseline exhaust noise level of 83 dB(A). It can be seen from Table 6.2 item (2) that the recommended single horizontal muffler by Donaldson successfully removed 3 dB(A) from the baseline level. Since exhaust was identified as one of the major sources of noise in the truck, further reduction was sought in exhaust noise level. Therefore, a Donaldson stack muffler was added that effectively reduced the discharge noise and brought the exhaust source noise level to 76 dB(A) as listed in Table 6.2, item (3). Despite the good results obtained with the Stemco muffler

TABLE 6.2 EXHAUST MUFFLERS EVALUATED

	MUFFLER MFR.*	MFR/IH PART NO.	IN DIA. OUT IN./mm	SYSTEM	BODY IN./mm	BODY LENGTH IN./M	OVERALL LENGTH IN./M	EVALUATED RATING dB(A)	BACK PRESSURE IN. HG./mm
1	Donaldson	MAM10-0004/256017-C91	4.00/102	SHVTP	10.12/257 Dia.	36.00/.914	39.25/1.0	83 (Base-line)	1.8/46
2	Donaldson	MAM10-0052/439797-C1	4.00	SHVTP	10.12/257 Dia.	27.75/.7	31.00/.79	80	1.9/48
3	Donaldson	439797-C1	4.00	SHVTP	10.12/257 Dia.	27.75/.7	31.00/.79)		
		AEM00-1193/871136-C1	4.00	Stack Mflr.	---	---	33.75/.86)	76	2.2/56
4	Stemco	9419	4.00	SHVTP	10x15/254x381 Oval	36.0/.914	39.0/.99	76	2.2/56
5	Riker	94006	4.00	SHVTP	9x14/229x356 Oval	35.0/.89	38.0/.97	85	1.5/38
6	Riker	10006	4.00	SHVTP	10.0/254 Dia.	36.0/.914	39.0/.99)	76	2.4/61
		871136-C1	4.00	Stack Mflr.	---	---	33.75/.86)		
7	Cowl	S40PR	4.00	SHVTP	11.75/299 Dia.	15.0/.381	27.5/.7	81	1.4/36
8	Cowl	XS40PL	4.00	SHVTP	---	---	---	81	1.3/33
9	Donaldson	459483-C1	4.00	SVVTP	10.0/254 Dia.	43.5/1.1	51.0/1.3	76	2.2/56
10	Donaldson	WOM12-0197	4.00	SHHTP	10.31x15.31/262x389 Oval	36.12/.917	42.0/1.07	78	2.8/71
11	Stemco	9419	4.00	SHHTP	10x15/254x381 Oval	36.0/.914	39.0/.99	76	2.4/61
12	Riker	10006	4.00	SHHTP	10.00/254 Dia.	36.0/.914	39.0/.99	86	2.2/56

* Manufacturer

(see Table 6.2, item (4)) it could not be used due to installation problems caused by the inlet, outlet location.

Cowl's "XS" series model silencer was also evaluated as the sample was supplied with recommendation. As shown in Table 6.2, item (8) only 2 dB(A) reduction was noted in the baseline exhaust source noise level.

6.5.1.2 SVVTP

The primary truck with SHVTP was experimentally converted to SVVTP to cover that configuration of the exhaust system. The optimum muffler No. 549483-C1 (Donaldson No. WTM10-0066) previously selected for COF4070A was installed for evaluation. SAE drive-by test results indicated an exhaust noise level of 76 dB(A) with this muffler. Pertinent information on this setup is listed in Table 6.2, Item (9).

6.5.1.3 SHHTP

Conversion of primary truck from SHVTP to SHHTP was made on an experimental basis. As shown on Table 6.2, Items (10), (11) and (12), alternate mufflers were evaluated. The feasibility study for ease of installation was carried out simultaneously with the noise evaluation of the mufflers. Although the Stemco muffler was quite effective, the installation was inconvenienced due to the inlet and outlet on the same end. Also, the location of the connection points were too close to each other to permit proper routing of the pipes.

The Donaldson muffler WOM120197 in item (10) was equally effective, plus the inlet and outlet were conveniently located in the opposing faces of its oval configuration. The feasibility study indicated that due to the large overall length of the muffler, it could not be used with 2000D 4x2, 132" (3.35M)

WB, and 2000D 6x4 144" (3.66M) WB and 150" (3.8M) WB.

6.5.2 Pipe Shell Noise Treatment

The exhaust manifold as well as the pipe from the manifold to the primary muffler were situated fairly close to the framerail in this chassis model. The exhaust resonator could not be located due to space congestion, and therefore its effect to reduce pipe shell noise could not be evaluated. However, a pipe radiated noise measurement was carried out by wrapping the pipe from the manifold to the primary muffler with vinyl barrier material. SAE drive-by test showed no measurable change in the truck exterior noise level, thus indicating that the pipe shell noise was low.

6.5.3 Fan and Cooling System

It may be recalled here that a simulated bellypan was used to treat the engine noise. The fact that the bellypan was mounted to the front bumper aroused suspicion about air flow restriction. Therefore, air flow measurements with and without simulated bellypan were taken for comparison. It revealed 2% loss in air flow with bellypan installed.

It was further proposed to evaluate bellypan effect on the cooling fan noise. Therefore, SAE drive-by tests were run with and without simulated bellypan and with the production fan setup. It showed a 2-3 dB(A) reduction in the baseline cooling system (fan) noise level with the bellypan installed.

Considerable reduction was realized in fan noise with the bellypan as a trade-off for insignificant loss in air flow. It was finally resolved to carry on the fan development work with the bellypan installed. For this reason a more practical bellypan was constructed by the Experimental Shop at IH Truck Division Engineering.

A detailed study of Fleetstar-D production history was also carried out to determine the number of various combinations offered in the cooling system. It revealed the following variations:

1. Three (3) different radiator core thicknesses.

2. Two (2) engine front ends, hence two fan ratios.

3. The engine with old front end had 1.00 in. (25.4mm) fan spacer with power steering and no spacer without.

4. The engine with new front end had 1.25 in. (32mm) fan spacer across the board.

Any combination of the above variations was so adjusted that 58% of the fan was always covered by the shroud with the old front end engine; and 17% of the fan was always covered by the shroud with the new front end engine.

It was beyond the scope of this project to cover every combination, neither did it seem possible to simulate them. The practical alternative was to extrapolate the results obtained on the primary 2000D development truck.

6.5.3.1 <u>Fan Spacing</u>

The development truck had an old front end engine without power steering, with 3.0 in. (76mm) radiator core thickness, and fan-to-core spacing of 3.0 in. (76mm). The production fan was 24.0 in. (610mm) in diameter, 6 blades equally spaced with a projected width of 2.4 in. (61mm). The production shroud was box type with a small lip at the opening.

The baseline air flow and noise level were established by taking measurements with the production fan and the sheet-metal bellypan. Since the fan in its original position was 58% immersed in the shroud, the spacers of three different thicknesses were fabricated to obtain 100%, 114% and 120% immersion as shown in Table 6.3. These spacers were installed successively and air flow comparison showed a 5% gain with only 1 dB(A) reduction in the fan noise level.

6.5.3.2 Commerically Available Fans

The Flex-a-lite Company provided one plastic and one steel fan. The evaluation of the plastic fan indicated about 20% loss in the air flow whereas the cooling system noise was reduced only 1 dB(A). The steel fan showed slight loss in the air flow but without any measurable difference in the cooling system noise level. (See Table 6.3)

The Schwitzer Company recommended a fan for 6-71N engine that was procured for evaluation. The projected width of this fan was 3.5 in. (89mm) and physically could not be installed because it was interfering with the crank pulley, hence it could not be evaluated.

6.5.3.3 Shroud Characteristics

Although all the factors involved in fan spacing were not separated, the development work in Section 6.5.3.1 pointed up to the fact that the use of spacers was moving the fan beyond the point of optimum location. Thus two ways were considered to treat the shroud that would provide 100% fan immersion which optimizes the fan location. They were to:

1. Find replacement shroud that would have necessary features of contoured lip and width sufficient for 100% fan coverage.

TABLE 6.3 - FAN SPACINGS & THEIR EFFECTS

FAN	SPACER THICKNESS IN/ mm	FAN CORE IN/mm	% COVERAGE	FAN NOISE LEVEL	AIR FLOW COMPARISON
433150-R91	----	3.00 / 76	58	82.0	REF.
433150-R91	1.00 / 25.4	2.00 / 51	100	81.0	5.4% Gain
433150-R91	1.25 / 32	1.75 / 45	114	81.0	5% Gain
433150-R91	1.38 / 35	1.62 / 41	120	81.0	5% Gain
#1641 FLEXALITE (PLASTIC)	----	3.90 / 99	---	81.0	19.7% Loss
#3324 FLEXALITE	----	3.2 / 81	---	82.0	2.6% Loss

2. Attach a contoured extension to the lip at the opening of the production shroud.

   Due to numerous variations affecting the fan shroud orientation, the length of contoured lip required for 100% fan coverage would vary too. Hence, instead of finding as many different shrouds with varying length of contoured lips, it was found convenient to attach a contoured extension to the production shroud.

The experimental sheetmetal shop fabricated a straight 1.00 in. (254mm) extension that was attached to the lip of the production shroud with small screws as shown with pointed arrows in Figure 6.7. The production fan was installed without any spacer (production setup) and air flow and noise measurements were taken. There was a 2-3 dB(A) reduction in the cooling system noise level but air flow loss of about 9% was also experienced. The sharp straight section was causing restriction in the air flow due to the resulting turbulence. Therefore, it was decided to provide a contour to streamline the flow as shown in Figure 6.8. The air flow measurement with the contoured extension showed 6% loss in air flow, a 3% gain over the straight section while the noise level showed about the same amount of reduction. The contoured extension was hence selected as the final treatment for cooling system noise.

6.5.3.4 Fan Clutches

A feasibility study was conducted for the installation of fan clutches. It was determined that the Horton clutch #9831 could be installed with the old front end (Pre-1970) of 6-71N Detroit Diesel engine, with and without power steering. The Horton clutch #9839 could be used with the new front end (Post-1970) of 6-71N engine, without power steering.

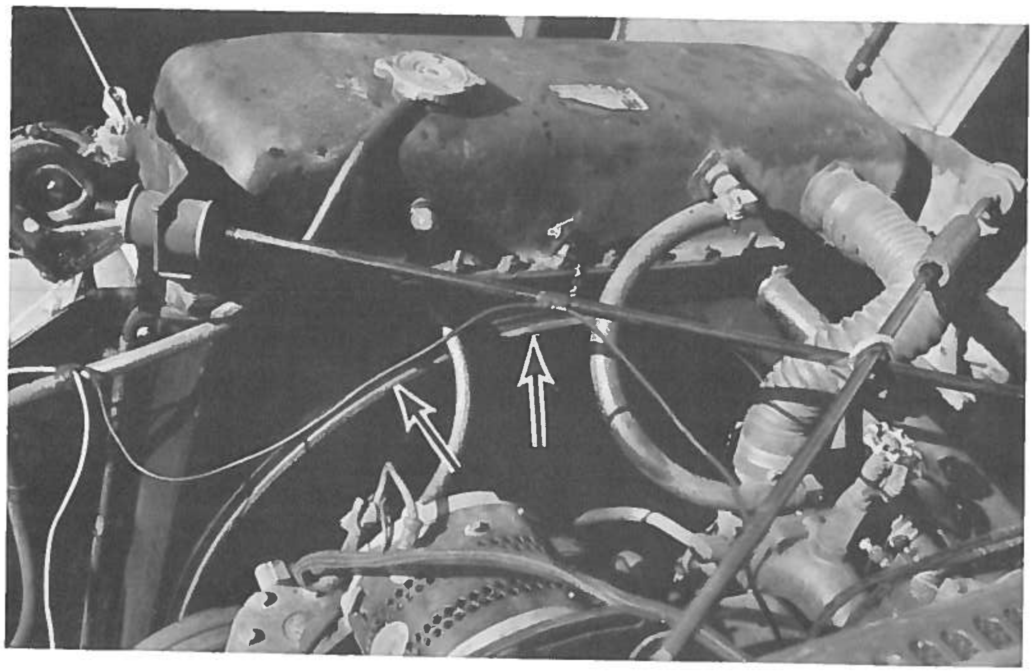


FIGURE 6.7 SHROUD EXTENSION - STRAIGHT LIP.

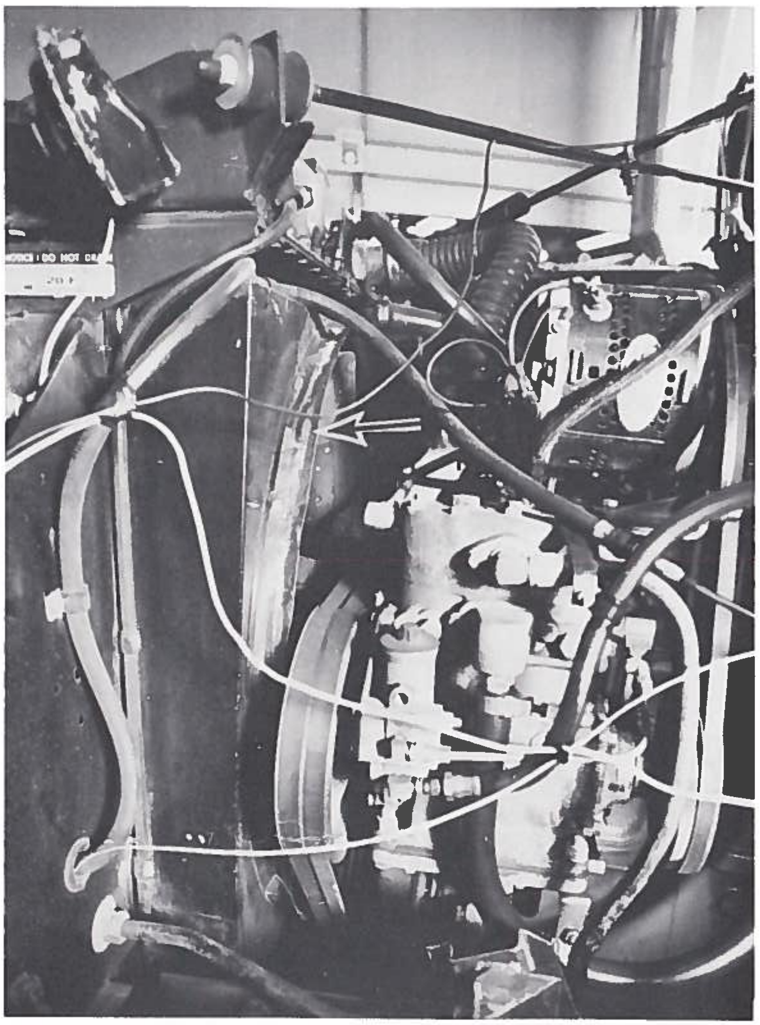


FIGURE 6.8 SHROUD EXTENSION - CONTOURED LIP.

6.5.4 Engine

The Detroit Diesel model 6-71N65 engine in 2000D primary truck is an inline 6-cylinder, scavenged-engine with a stamped sheet steel oil pan. The engine performance curve is given in Appendix K. Engine source identification was carried out not by wrapping but by treating it with adequate noise reducing components. Detroit Diesel Allison Company was contacted with a request to share the development program by making recommendations to reduce the engine source noise. They informed that nothing has been made available commercially, however, their own research work had pointed up to the probable alternatives of covers and panels, or a chassis underpan. Greater emphasis was placed on the chassis underpan (bellypan).

Since an acoustically hard surface abounds the measurement zone between the truck and the microphone, sound energy is reflected from this hard surface. Part of the sound energy travels directly from the source and part of it, incident upon the hard surface, is reflected and reaches the microphone as shown in Figure 6.9. Underframe shielding (bellypan) can therefore be used to interrupt the path of energy incidence thereby reducing the amount of reflected sound energy resulting in engine source noise reduction. This is demonstrated pictorially in Figure 6.10. As there was nothing readily available for engine treatment, simulation of engine enclosure and bellypan was carried out by using vinyl barrier material.

6.5.4.1 Simulated Bellypan

The frame mounted bellypan simulation was accomplished by using vinyl barrier material taped to the bottom flange of the frame rail and held with nylon straps. It extended rearward from the bumper in the front to the clutch housing

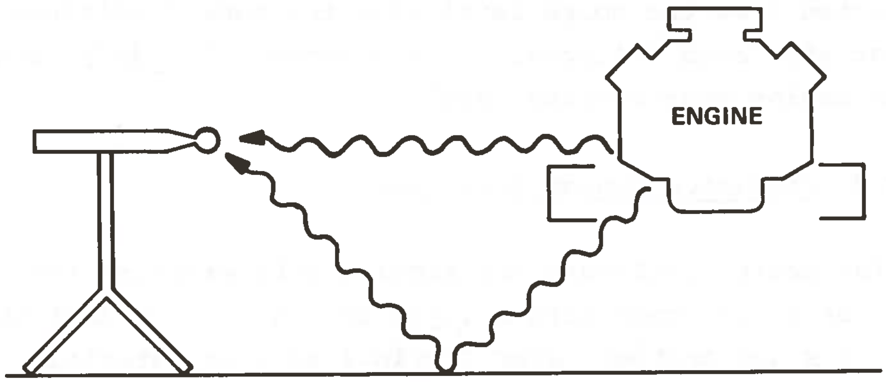


FIGURE 6.9 SOUND ENERGY TRAVEL PATHS.

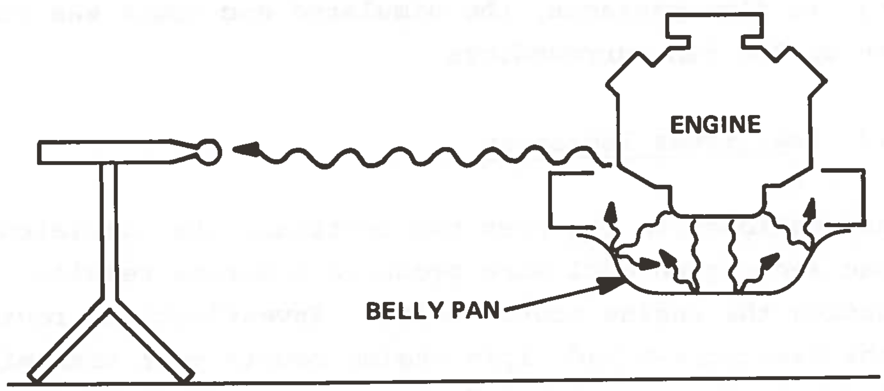


FIGURE 6.10 EFFECT OF BELLYPAN.

in the rear, as shown in Figure 6.11. The SAE drive-by tests were run with artificially silenced exhaust and intake silencer, fan removed. This noise level was acoustically subtracted from the noise level with the same conditions without simulated bellypan. It indicated a 1.2 dB(A) reduction in the engine source noise level.

6.5.4.2 Simulated Engine Enclosure

The engine enclosure was simulated by wrapping the engine under the hood with a layer of 1.0 in. (25.4mm) thick fiberglass and another layer of vinyl barrier material, as shown in Figure 6.12. The hood was then closed and drive-by test was run per SAE J366b. Half a dB(A) reduction was realized in the engine noise level, not significant enough for further consideration. This was not a practical solution but merely an effort to reduce engine radiated noise to prepare the vehicle for development work. Since it was closing air flow passages, the simulated enclosure was removed to open up the fan surroundings.

6.5.4.3 Fuel Tanks Isolation

As mentioned in the previous sections, the simulated bellypan and engine enclosure produced moderate results in reducing the engine source noise. Investigations revealed that the Fleetstar-D had rigid engine mounts that transmitted vibrations to frame, cab and fuel tanks. Near field noise measurements were taken around the periphery of the truck in an effort to pinpoint the "hot spots". The noise level was peaking at the position where the sound meter was in line with the fuel tanks. This was noted at both right and left sides where fuel tanks are located in this chassis model. Fuel tanks were then covered with leaded vinyl as shown in Figure 6.13 and near field measurements were again

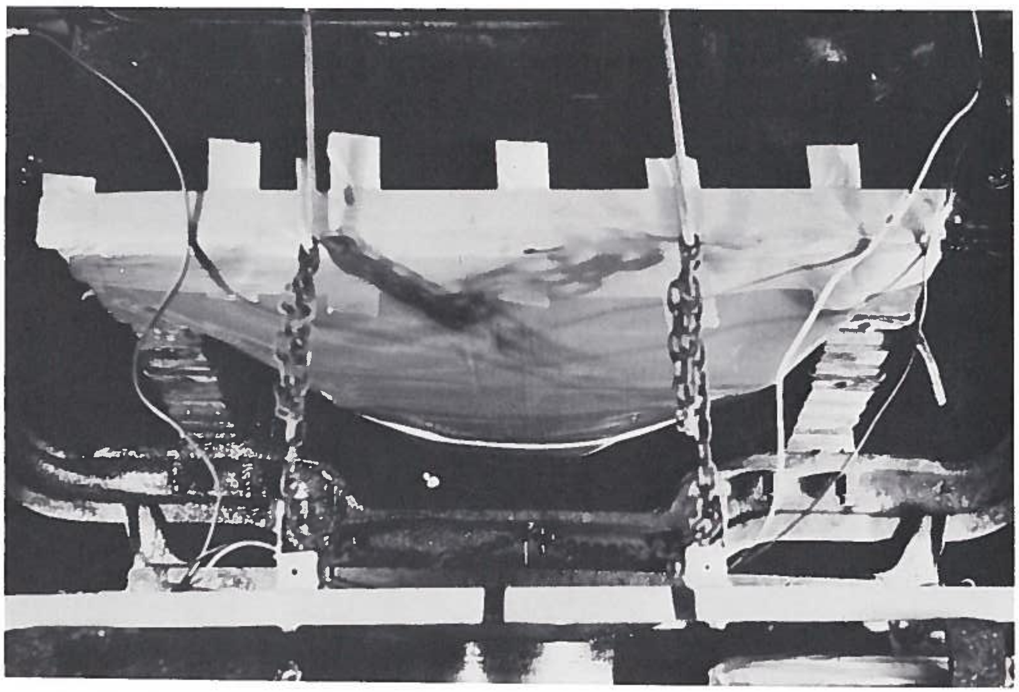


FIGURE 6.11 SIMULATED BELLYPAN.

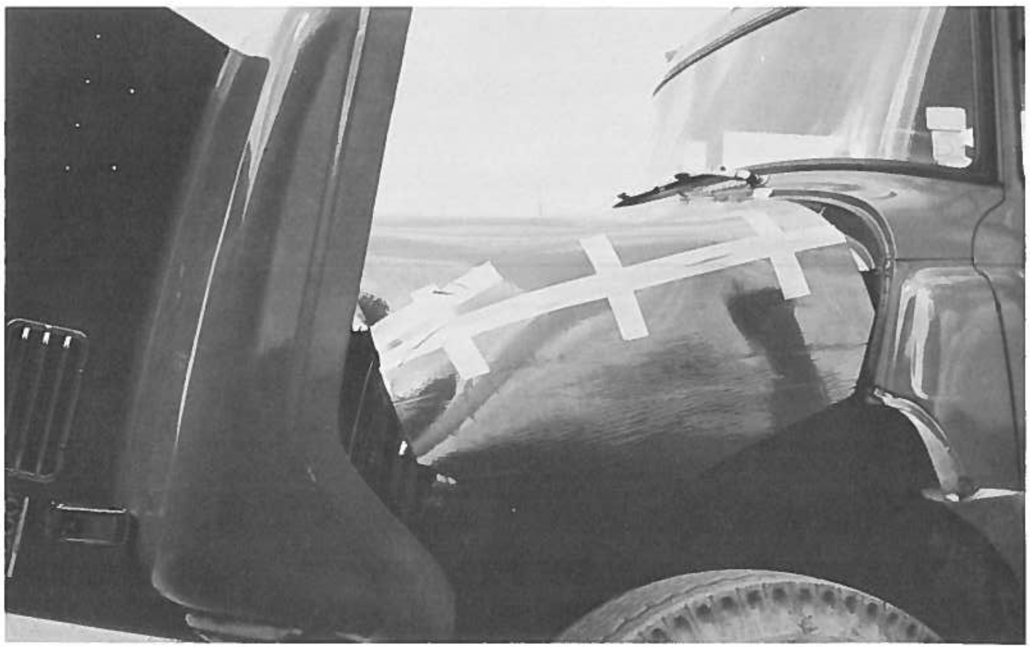


FIGURE 6.12 SIMULATED ENGINE ENCLOSURE.

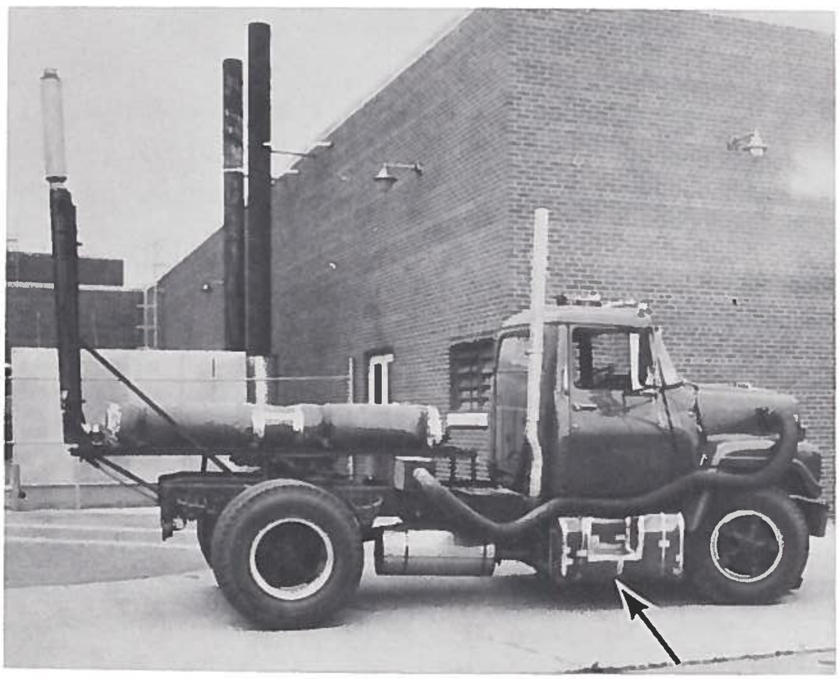


FIGURE 6.13 FUEL TANK ISOLATION.

taken. It depicted a 2-3 dB(A) reduction in the peak noise level. Next, the SAE drive-by test was run with wrapped fuel tanks that evinced 1 dB(A) reduction in the engine source noise level.

The effect of the amount of fuel in the tanks was also determined by making SAE drive-by runs with full and quarter full tanks. No noticeable difference was seen.

In the final condition, the fuel tank mounting straps were isolated using isolating straps instead of vinyl barrier material covers that produced equally effective results. The isolating straps were installed between fuel tank and fuel tank mounting straps. This was considered as part of engine source noise treatment since the noise caused by fuel tank vibration was lumped in the engine source noise.

6.5.4.4 Sheetmetal Bellypan

As indicated earlier from the evaluation of the simulated bellypan, this method was effective in reducing engine and cooling system noise while not significantly reducing the cooling system air flow. A more practical bellypan was therefore fabricated, as shown in Figure 6.14. It extended from the front bumper rearward to the rear face of the clutch housing. SAE drive-by test runs repeatedly proved the significance of the bellypan from the standpoint of exterior noise reduction (see Table 6.4), but its impact on cooling and feasibility of installation had yet to be considered. Furthermore, the acoustical energy was being reflected and intensified by the bellypan, resulting in about a 2 dB(A) increase in the cab interior noise level. Hence the selection of bellypan was contingent upon satisfactory evaluation of its impact on cooling, successful cab interior treatment to meet BMCS regulation, and the ease of fabrication and installation.

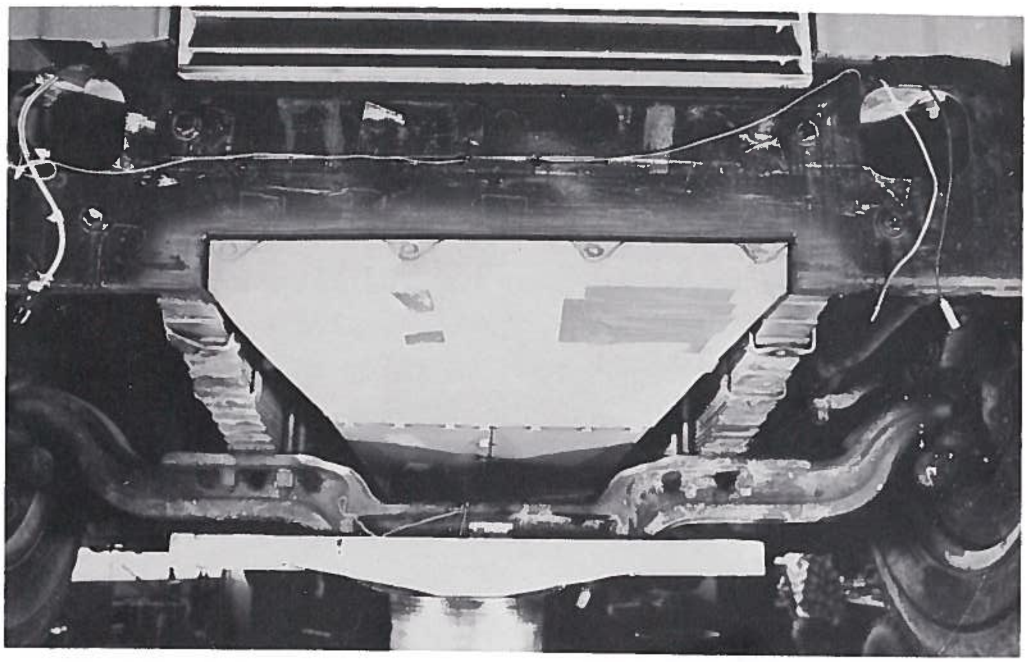


FIGURE 6.14 EXPERIMENTAL SHEETMETAL BELLYPAN.

6.5.4.4.1 Cooling Evaluation

The air flow measurement taken previously with sheetmetal bellypan had shown a 6% loss compared to the baseline measurement. The cooling system for 6-71N65 Detroit Diesel engine was designed to meet the worst operational air temperature condition which is specified by engine manufacturer to be 122 degree Farenheit air-to-boil. Air (temperature)-to-boil (ATB) is the ambient temperature at which the engine would boil (coolant temperature of 212^{o}F) if operated at full load, rated RPM, and moving at 15 mph (24 km/h). Therefore, the effect of bellypan on cooling was further evaluated by running cooling test in the IH Hot Room Lab facility at peak horsepower and peak torque engine speed, that is, 2100 rpm and 1600 rpm respectively. The hot room facility and test method is described in Appendix M. The cooling runs with and without bellypan indicated loss of 4^{o} air-to-boil with the bellypan. The test thus suggested that a bellypan could be feasible provided cooling initially was not marginal.

6.5.4.4.2 Cab Interior Treatment

The development work carried out under the subject contract basically covered the treatment of major noise sources contributing to the truck exterior noise. However, the use of bellypan in 2000D for engine noise treatment caused the cab interior noise level to go up by about 2 dB(A). Hence some trucks may require cab interior treatment with bellypan installation for BMCS compliance. IH, through its Fleet Letter No. SLF 7421, dated April 15, 1974, had published the suggested methods to reduce the interior noise levels. It is presently being offered as a retrofit kit by IH Service Organization. Cab interior of 2000D with bellypan was thus treated in steps with this kit, see Figure 6.15. The BMCS stationary test showed that the cab interior

FIGURE 6.15 INTERIOR TREATMENT.

noise level with partial treatment was reduced to 89 dB(A) as compared to 96 dB(A) with bellypan and without cab interior treatment.

6.5.4.4.3 Bellypan Final Design

The bellypan design was then considered for its installation with minimum effort. Although the bellypan was proposed to be used with only one model-engine combination of 2000D with 6-71N Detroit Diesel engine, the multiple variations in the components offered in this model made it tedious to design a standard bellypan to accommodate all. Also, the location of filter and starter on the left side did not permit a symmetrical shape to be maintained. More importantly, the original chassis design permitted about 5/16 in. (8mm) clearance between oil pan and front axle beam at full bounce, metal to metal. That is, the bellypan had to be located within 5/16 in. of the oil pan for proper clearance. Further, the oil pan was situated at a lower level compared to the front bumper which required the bellypan to be designed to contain different planes in its installed condition. The front bumper had two different locations due to two different engine positions which meant two different sets of mounting holes.

In view of the problems enumerated, several compromises were made in the design: An adequate opening for the oil filter was provided with an inspection cover. An additional opening was provided for the oil drain and the drain plug was lowered close to the bellypan by using a 90° elbow for easy access. It was also resolved to mount the bellypan in the front to the radiator mounting crossmember instead of the front bumper since the crossmember location was the same regardless of engine positions. Reliefs were also provided for starter, spring stops and spring shackles.

The main body design of the bellypan consisted essentially of a three piece construction, see Figure 6.16: A middle section containing two distinct planes and tab weld nuts on both sides to mount the left and right sections. The left and right sections were bent up towards the chassis framerails, and were mounted at two different locations. The front side mounts consisted of a bracket tack-welded to the side panel on the left and to the oil filter inspection cover on the right, bolted with isolators to an L-shaped bracket, fastened to the framerails. The rear side mount was made at the rear end of the side panels utilizing the existing holes in the framerail flanges. The center panel was mounted in the rear and front to the existing crossmembers by using two isolated U-bolts at each location. Figure 6.17 shows the bellypan installed on the chassis.

6.6 ENGINE PANELS

Detroit Diesel had informed IH that they have been doing test and engineering development work on 6-71N engine panels to reduce engine mechanical noise. But incoherence was noted between dynamometer results and results obtained in the total truck environment from the SAE pass-by test. This was explained by the fact that the majority of Detroit Diesel engines mechanical noise is transmitted through the top of the engine, and only a small part through the oil pan. Thus the normal shielding of the cab reduced the effectiveness of the panels. A set of engine block panels was furnished for evaluation under the retrofit program. The oil pan treatment was not a part of it.

The scavenge blower cover was also included with the set of block panels. They were constructed from laminated steel with open cell foam rubber backing. The block panels, as provided, could not be installed since they were designed for a different chassis model but for the same engine, and

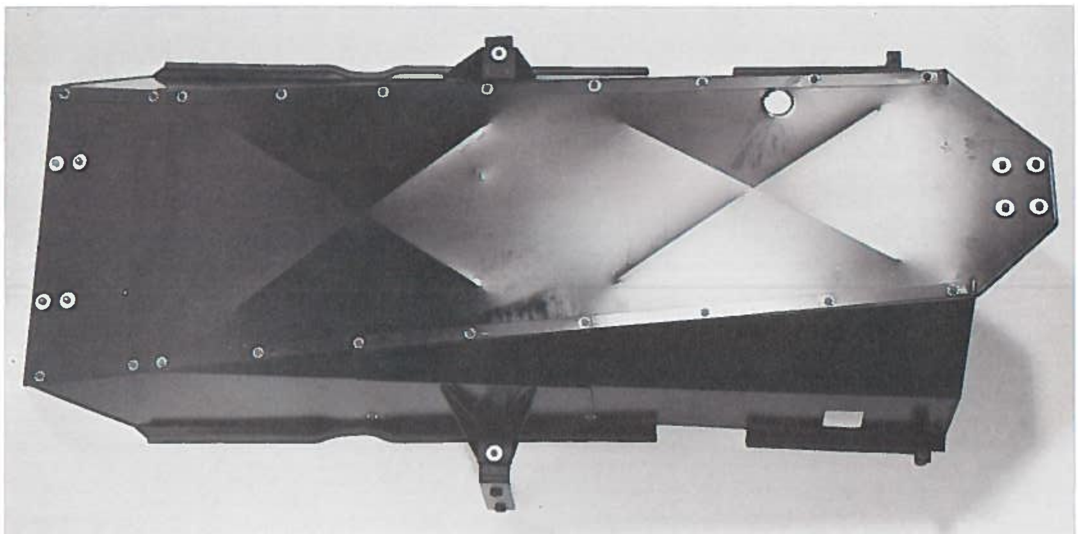


FIGURE 6.16 FINAL BELLYPAN.

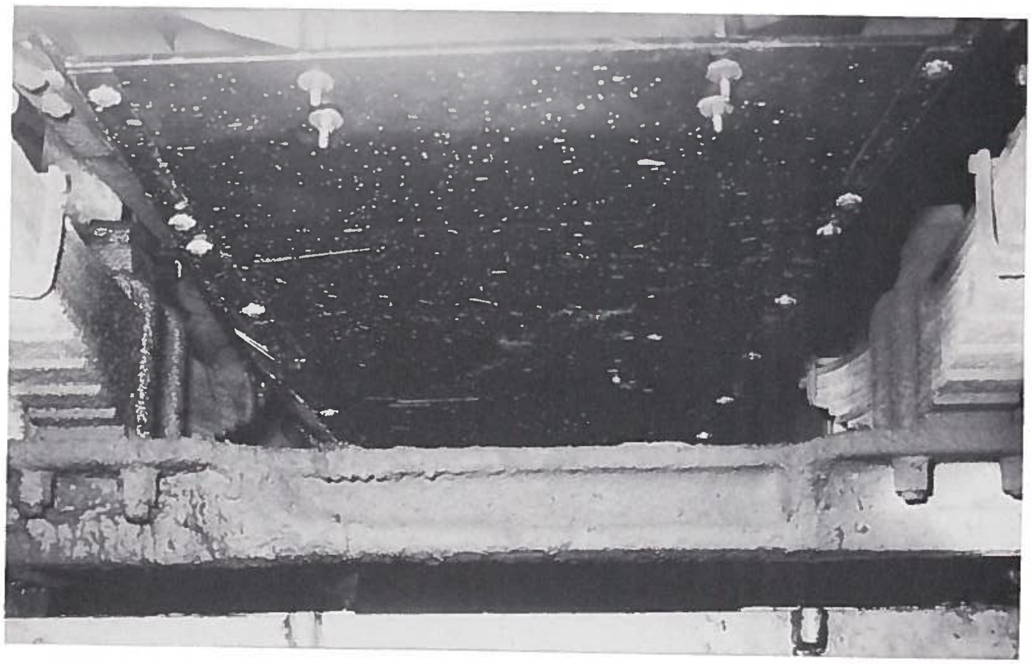


FIGURE 6.17 FINAL BELLYPAN INSTALLED.

required extensive modifications. Particularly at the left side of the engine block where the scavenger blower assembly was mounted, the block panels had to be cut in many pieces as shown in Figure 6.18. Even after that, the closeness of framerail to the chassis, and several accessories mounted to the engine block on both sides presented numerous installation problems.

SAE drive-by tests were conducted to determine the effectiveness of the sound panels. It did not indicate any measurable reduction in the engine noise level. The results were compatible with those Detroit Diesel reportedly found according to their tests in the total truck environment.

6.7 FINAL KIT EVALUATION

Based upon the evaluation of the commercially available components and the components developed under the contract for reducing the source noise, the most effective components were selected to make the target figure of 83 dB(A) for total truck noise level. Hence, for the primary truck 2000D with 6-71N65 engine and single horizontal muffler, vertical tailpipe, the selected noise reduction components were as shown in Table 6.4.

TABLE 6.4 - FINAL KIT COMPONENTS

NOISE SOURCE	COMPONENT DESCRIPTION	MFRS/IH PART NO.	EVALUATED NOISE RATING, dB(A)
Exhaust	1. Primary Muffler + 2. Stack Muffler	MAM10-0052/439797-C1 + AEM00-1193/871136-C1	76
Fan	Shroud Ext. + Bellypan	New	77
Engine	Bellypan + Fuel Tank Isolation	New	79

The evaluated noise ratings of each selected component were acoustically added to obtain the theoretically predicted

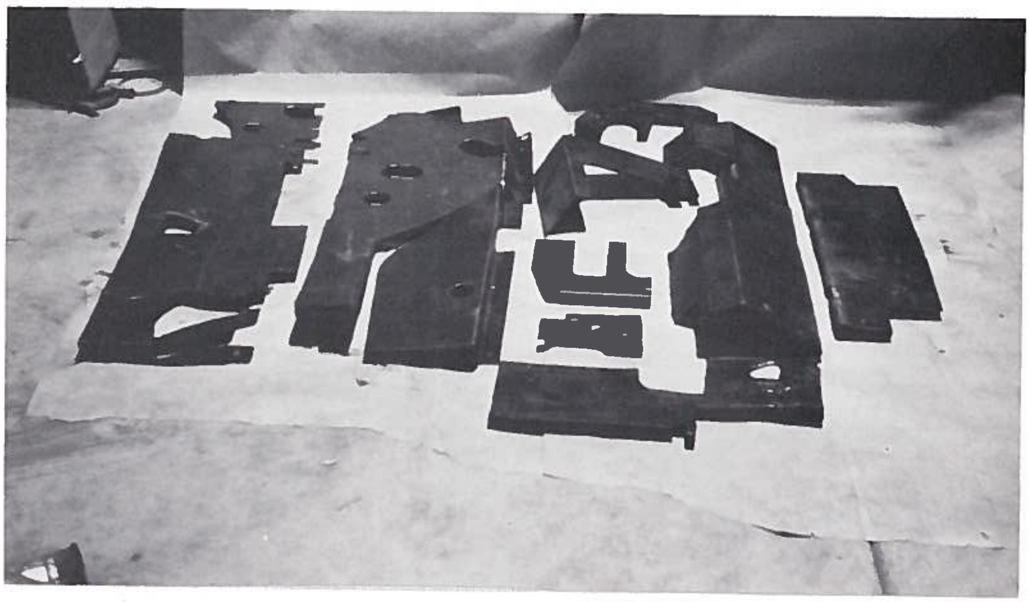


FIGURE 6.18 ENGINE BLOCK PANELS.

total truck exterior noise level of 83 dB(A) as shown in Figure 6.19.

6.7.1 Exterior Noise

The selected components to quiet the major noise sources were installed and the SAE pass-by run was made to find their cumulative effect on the total truck noise level. The maximum SAE average of total truck noise level was found to be 83.5 dB(A), shutters closed and open, which was in conformance with the theoretically predicted level within the tolerance range. The selected components were thus considered to be the optimized noise reduction components, and final data acquisition was completed by running all the baseline tests as listed in Section 3. Figures 6.20 and 21 show the final truck exterior noise level versus position and frequency respectively.

6.7.2 Interior Noise

Interior noise level was measured according to the BMCS recommended procedure with the selected subsystems installed. The results indicated a 2 dB(A) increase over the baseline interior noise measurement of 94.0 dB(A). It was therefore resolved to treat the cab interior in stages with the suggested methods previously developed by IH to reduce the cab interior noise (Fleet Letter No. SLF 74-21, dated April 15, 1974). Cab leakage was first treated by sealing all holes and openings in the engine and the cab side of the firewall and floor panels with body sealing compound (dum-dum material). New boots were also installed for clutch and accelerator pedals, and steering column seal was also replaced. Barrier and absorption material was used to cover floor panels. The material was cut to fit the floor mat pattern, so that one layer of absorption material was sandwiched between the layers of barrier material. Finally the rear cab panel was sealed and treated with fiberglass

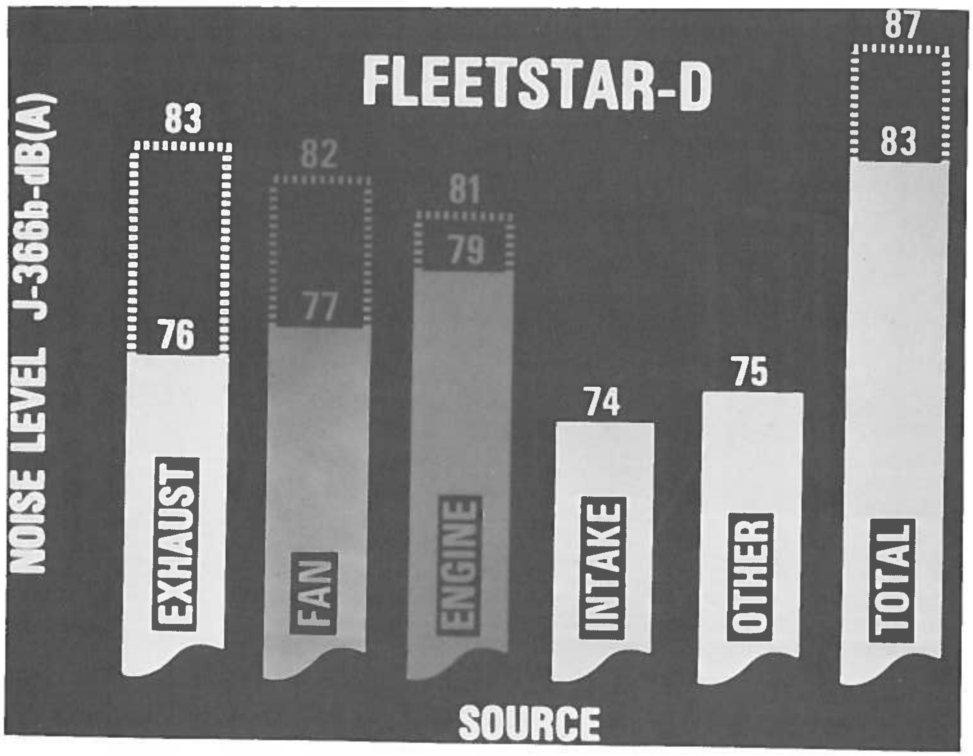


FIGURE 6.19 FINAL SOURCE NOISE LEVELS.

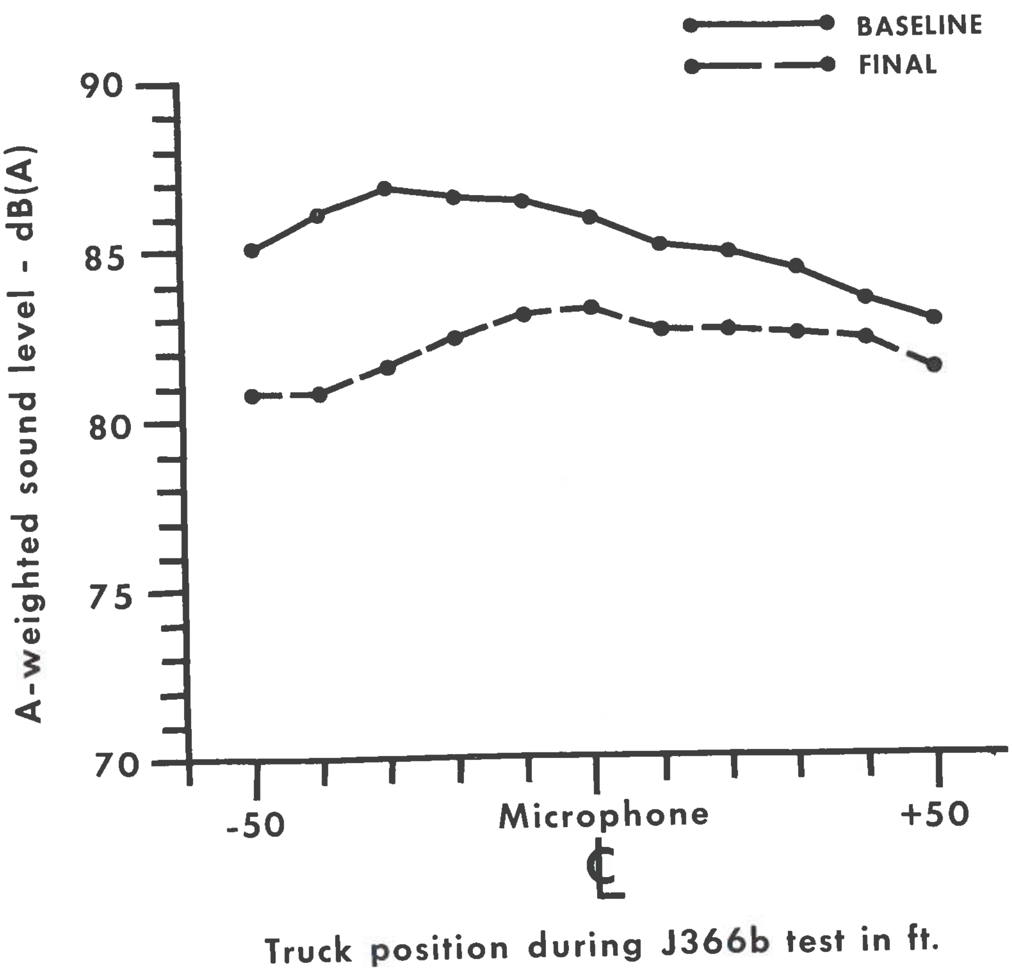


FIGURE 6.20 BASELINE & FINAL NOISE LEVELS VS. TRUCK POSITION.

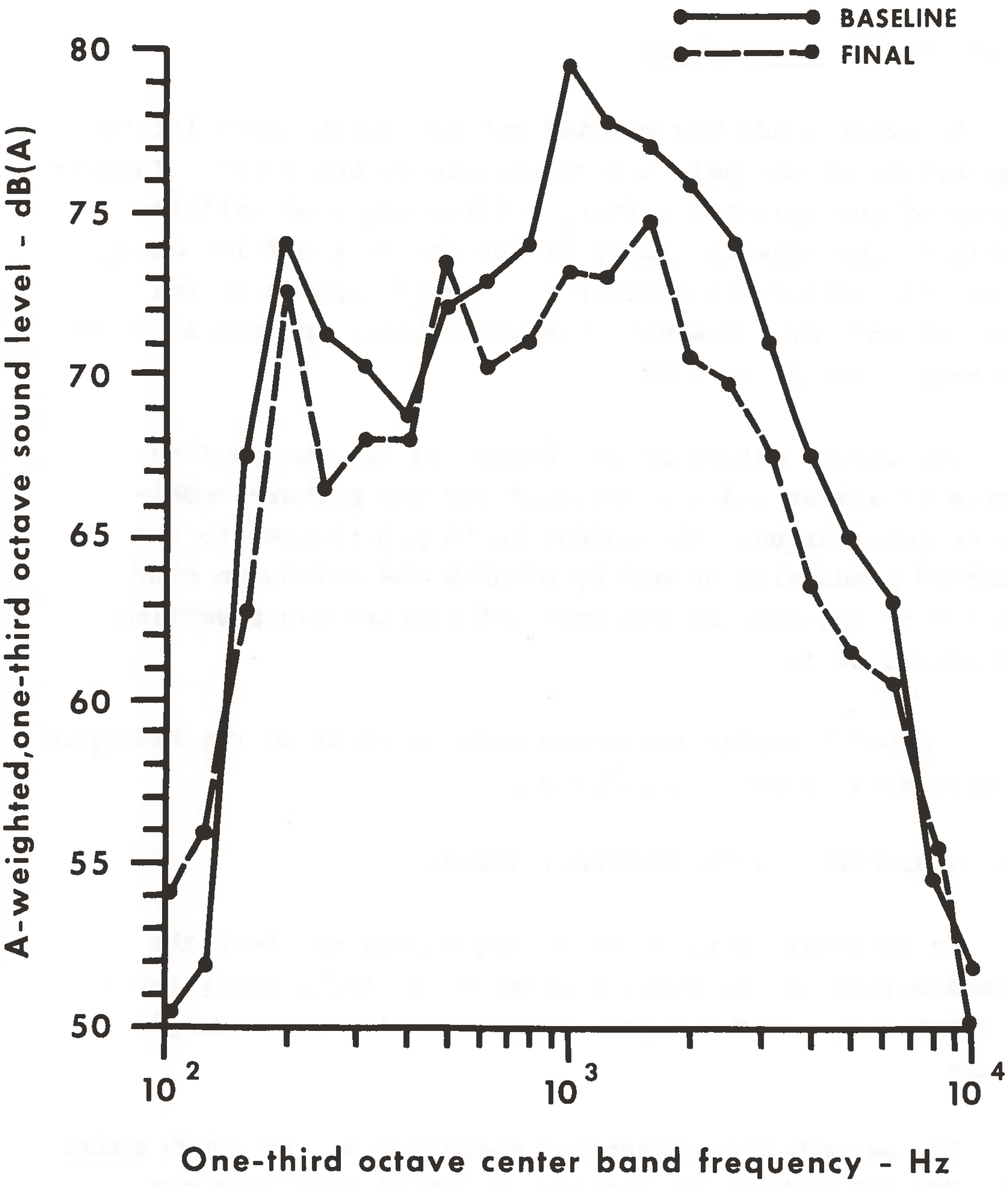


FIGURE 6.21 BASELINE & FINAL NOISE LEVELS VS. FREQUENCY.

insulation. The cab interior noise level was then measured per BMCS regulation to be 89 dB(A), see Figure 6.22.

6.7.3 Design Feasibility

A design study was carried out to assess installation feasibility of the selected components in the field. Installation of the selected primary muffler required drilling a hole in the chassis framerail for the rear muffler clamp, since this muffler is shorter in length compared to the original muffler. However, the same clamps are reused since the body diameter is same.

The shroud extension was developed for the cooling system treatment and was designed for the primary model-engine combination. The extension is pop riveted to the standard production shroud by sliding the extension over the lip at the opening and does not require disassembling the shroud or fan.

A careful design study was made to finalize the bellypan as discussed in Section 6.5.4.4.3.

6.8 APPLICABILITY TO SECONDARY TRUCKS

An essential part of this program was to check the spreadability of the results obtained on the primary truck of 2000D with 6-71N65 engine to the similar (secondary) trucks.

The secondary combinations consisted of the 2000D model with NHC-250 and NH-230 engines as established from the population study discussed earlier in Section 4. Another combination of 2000D with 6-71N, with N-60 injectors, was similar to the primary combination except the injectors, hence the same noise reducing components could be used.

APPENDIX A

N. A. Miller

NOISE DATA ACQUISITION AND REDUCTION SYSTEM

The Truck Noise Data Acquisition and Reduction System at International Harvester is a totally automated drive-by noise test facility. The rationale upon which that system was based and a description of the components selected will be presented.

The following criteria were established for the system. First and most important, the overall "A" level values in terms of SAE J-366a had to be provided. Secondly, it was determined that a combination of physical source identification along with one-third octave data reduction would provide adequate information for treatment of individual sources. Third, simultaneous readings for the right and left side of the vehicle had to be provided not only for development information but in order to efficiently utilize the Sound Pad facility. Fourth, the data should be presented on the basis of truck position so that noise directivity could be ascertained. And, last, it was preferred to avoid having anyone but the driver at the Sound Pad. This then meant that some provisions had to be made for monitoring when full throttle was established and when maximum rated engine speed was reached with respect to vehicle position. Provisions also had to be made for transmitting data to a remote location where it would be processed.

After considering several different approaches in light of the requirements outlined above, it was determined that the best approach was to use permanently mounted outdoor microphones at the Sound Pad site. The signal would be amplified and then transmitted via hard wire to computer controlled real time analyzers in the Vehicle Dynamics Building (Fig. 1 - black arrows indicate microphones; white arrow shows location of Vehicle Dynamics). The real time analyzers provide the overall "A" weighted noise levels to determine compliance to legal requirements. The one-third octave information is used for development work such as frequency source indentification.

The system selected is capable of eight SAE J-366a drive-by tests per hour (64 per 8 hour day). This rate is made possible by testing two vehicles in the time ordinarily required to test one. The test site is constructed so that data can be taken on one vehicle while the other is turning around. Construction of the site also provides for simultaneous noise measurements from both sides of the vehicle. Computer logic is used to keep the data for each vehicle properly categorized. Output from the system is a printed summary of one-third octave and overall "A" weighted peak noise levels and the positions at which they occurred. A data output option is available that yields a three dimensional plot of level vs. frequency vs. truck position. Both the printed summary and the plot provide

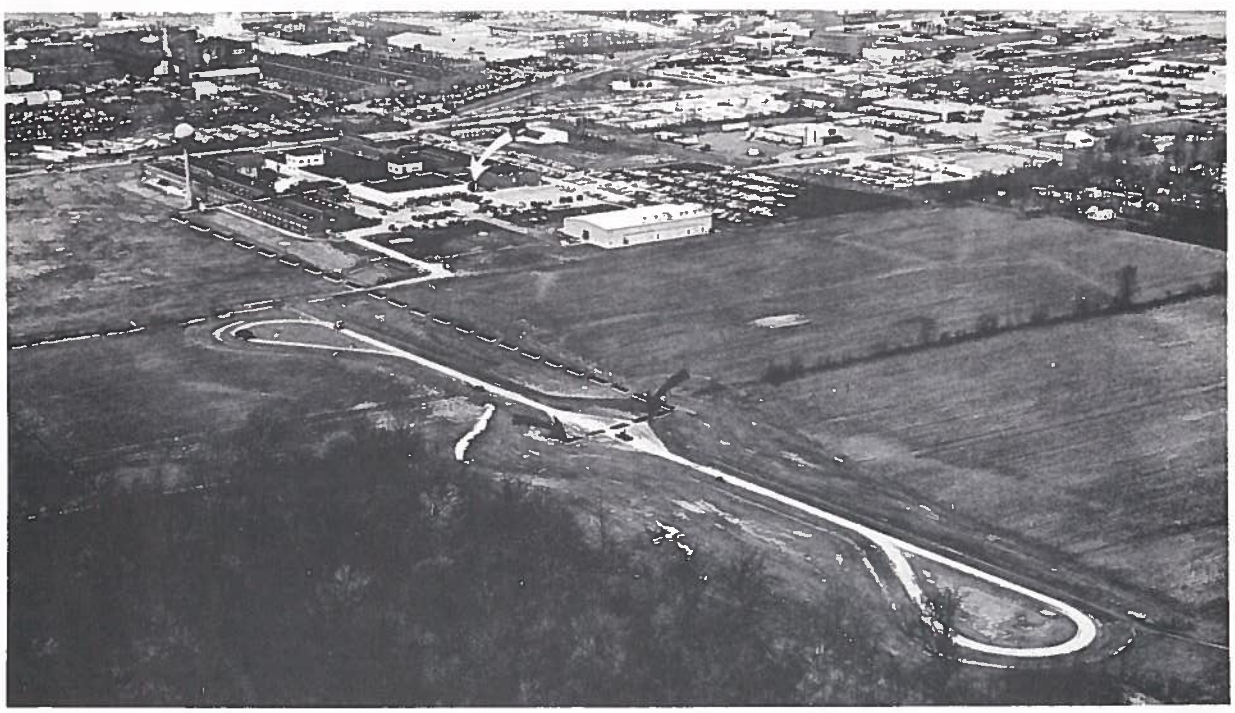


Fig. 1 - Noise test facility

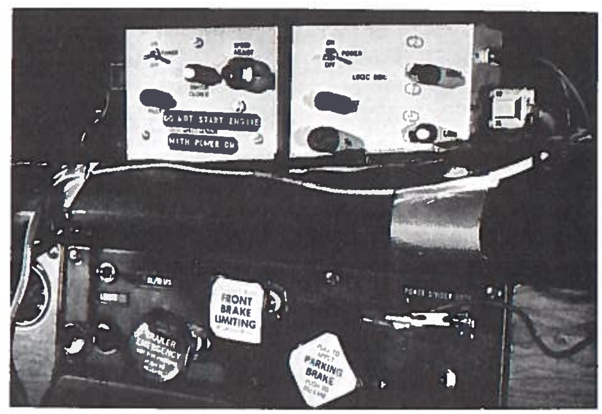
data for the left and right sides of the vehicle.

Each major component of the system was selected on the basis of the criteria that had been established. The remainder of this discussion describes the contribution that each component makes toward meeting the overall criteria for the Noise Data Acquisition and Reduction System.

In order to fulfill the requirement for vehicle noise levels with respect to truck position, some means had to be provided for the computer to know exactly where the truck is as it moves along the Sound Pad. This system, developed at International Harvester Truck Engineering, consists of two lines of parallel wired magnetically actuated reed switches. Each line of switches is installed in plastic tubing and set in a shallow trough 15 inches from the roadway centerline. (Fig. 2) The trough puts the switch tubes below the normal surface which allows for easy snow removal and having the trough open facilitates maintenance. The switches are wired and installed such that there is a switch every five feet. The tubes are 200 feet long with 41 switches in each tube. For the sake of computer logic, the switch lines are staggered such that the switches and one line are six inches longitudinally from those in the other line. The switch tube on the right side of the vehicle is used for vehicle position indication. The switch tube on the left side is used to determine test parameter acceptability, i. e., acceleration point and point of maximum RPM.

The reed switches are actuated by electromagnets slung from the front bumpers of the test vehicles. (Figure 2) The magnet on the right side of the vehicle is "on" continually as the vehicle passes through the test site. Each time the magnet passes over a switch, a pulse is sent to the computer and the computer reads the real time analyzers. For each switch actuation, the overall "A" weighted level and 22 one-third octave band levels (100 Hz through 12.5 KHz) are taken for each side of the vehicle. A total of 40 readings are taken for each side of the vehicle for each pass. The first switch actuation is used to start the computer processing and define vehicle direction. The first data reading is taken on the second switch. The computer counts how many readings have been taken to assure that the switches are operating properly. The magnets are constructed such that their width defines the lateral error that can be accepted. If the truck is too far off center, the magnets do not actuate the switches.

The left side magnet is "off" when the vehicle enters the test area. It is controlled through an on-board logic system (Fig. 3) that switches the magnet "on" when full throttle is established and then switches it back "off" again when maximum rated speed is reached. The computer monitors the switch impulses from the left side switch tube and compares them to the position of the truck based on the right side tube. In this way, the computer can determine whether or not the desired parameters have been satisfied. A major advantage of this type of system is that the physical parameters of the test can be varied by simply changing the logic in the computer. For example, J-366a requires that the vehicle start to accelerate at 50 feet before microphone centerline and reach



On board logic system

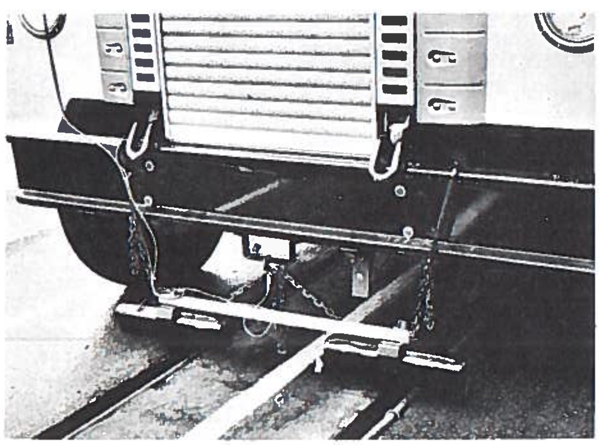
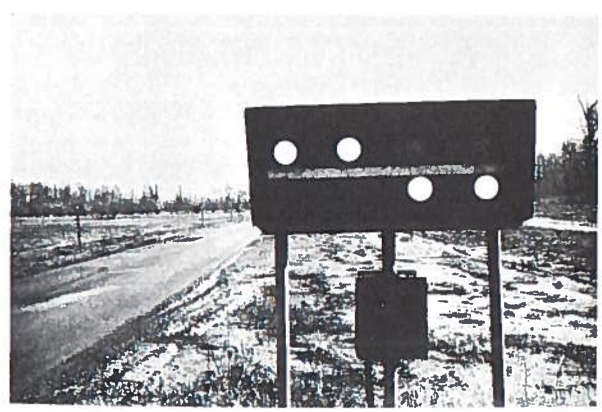


Fig. 2 - Reed switch tubes & electromagnets



Acceptability lights at sound pad

Fig. 3 - On-board logic and acceptability lights

maximum rated speed between 10 and 50 feet past microphone centerline. For purposes of development work, a shorter end zone may be desired to provide better test consistency. All that is required is a change of input to the computer. For example, the end zone can be changed from 10 to 50 feet past microphone centerline to 20 to 30 feet past microphone centerline.

The microphones used are outdoor type, permanently mounted and weather protected. (Fig. 4) The signal goes from the microphone (white arrows) to an amplifier (black arrows) and then through approximately a half mile of cable that terminates in the Vehicle Dynamics Building. Here the signals enter one-third octave real time analyzers (one for each side of the vehicle). The whole process is controlled by a mini computer with a 12K core memory. (Fig. 5)

As shown in Figure 1, the track is a straight line with turn around loops on each end. When a truck is running east, the south microphone is on the right side. When truck is running west, the south microphone is on the left side. The same relationship exists with the switch tubes. The computer provides the logic for reversing all the functions when the truck changes directions.

The light panel in the upper right hand corner of the computer console is used to give the operator updated information on what the trucks are doing at the Sound Pad. The eight lights on the left side of this rack tell whether or not the vehicle is meeting the test parameters. If all the lights are green (lower four) the parameters were fulfilled. If the first light is red, acceleration was made too soon. If the second light is red, it was made too late. If the third light is red, the maximum rated engine speed was reached too early; and, if the fourth light is red, it was reached too late, or the vehicle was too far off center. This same information is provided to the driver through the use of the same configuration of lights approximately 200 feet from microphone centerline at each end of the Sound Pad (Fig. 3). The remaining lights on the console are used to show the operator which truck is running, what direction it is going, and how many passes have been completed.

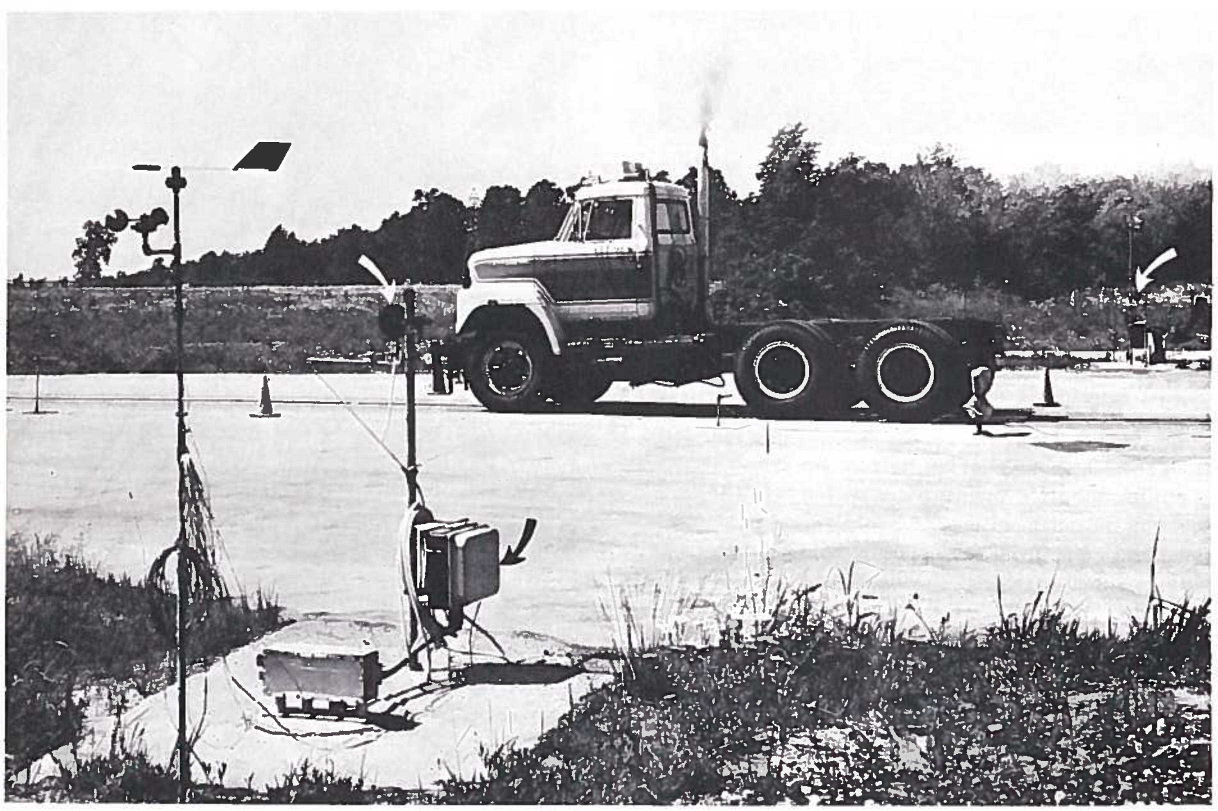


Fig. 4 - Outdoor micropones at sound pad

Fig. 5 - Truck noise data acquisition and analysis system counsel

Fig. 6 - Teletype for input

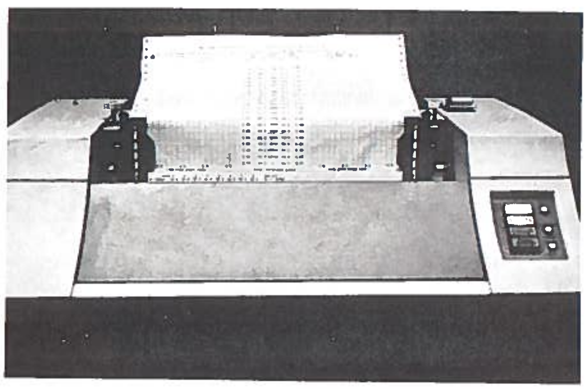


Fig. 7 - Line printer for printed output

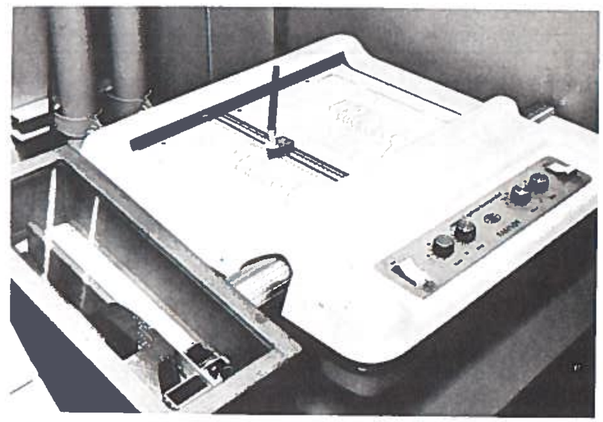


Fig. 8 - Tape reading plotter

Programs are loaded through the high speed paper tape reader and inputs are given using a standard teletype. (Fig. 6) Output is provided by a table top line printer (Fig. 7) and high speed paper tape punch. After the printed output is complete, the output sheet is removed from the printer and placed on a plotter with a paper tape reader (Fig. 8). The computer provides a paper tape containing the plot information, and the plot is completed off-line so that the computer can be used for the next test.

Considerable slack time exists after the test vehicle passes the measurement area and then proceeds to turn around and come from the opposite direction. Therefore, ability to run two vehicles simultaneously was added to the system. While one vehicle is turning around, the second one is being tested. The computer keeps the data from the two vehicles separated.

Figure 9 shows a typical input sheet for the drive-by test sequence. The vertical line drawn on the input sheet separates computer provided information and questions with operator provided information and answers. Information to the left side of the vertical line is provided by the computer; that to the right by the operator. "First Vehicle ID" is used to define the first truck being tested. Shutter information is then provided by the operator. "Open", "closed", or "none" are the standard responses. The "Description" area is used to provide either further description of the vehicle or for modifications that help identify the value of this particular test. Next, the computer asks whether or not a plot will be needed. If the response is "yes," then the plot tape is provided, and the summary information is printed in the center of the output sheet. If the response is "no," no plot tape is provided and the summary information is printed on the left side of the page. The "MPO" question deals with whether or not a Modeling Program Output is required. This is used in conjunction with source identification development tests. The output consists of a paper tape used as input for a vehicle noise modeling program in another computer. The "Gates" question deals with whether or not the computer will be required to determine if the required acceleration-maximum engine speed parameters are being reached. If the answer is "yes," these parameters are considered. If the answer is "no," they are not. If something besides standard J-366a

D	
FIRST VEHICLE ID	2070A NTC-335 SHV
SHUTTERS	OPEN
DESCRIPTION	#866 OIL SUMP COVER STANDARD EXHAUST
PLOT ?	YES
MPO ?	NO
GATES ?	NO
PASSES ?	8
TEST #012174-001	
SECOND VEHICLE ID	4070B #542
SHUTTERS	OPEN
DESCRIPTION	BASELINE RUN ENL
PLOT ?	YES
MPO ?	NO
GATES ?	YES
STANDARD POSITION?	NO
ENTER WHERE 11223344	11123032
PASSES ?	4
TEST #012174-002	
TEMPERATURE	34
WIND SPEED	ST10W-
TIME 7:26:32	

Fig. 9 - Input sheet

parameters are desired, the critical switch numbers are entered in sequence at this point. (Second vehicle Fig. 9)

The "Passes" question deals with how many passes are to be run in the test. One, four, or eight passes can be selected. The test run numbers are assigned by the computer and cannot be duplicated. The number consists of a date description contained in the first six numbers, and the last three digits are sequenced as tests are run. The first test of the day is 001, the second test 002, and so on.

The same information is then entered on the second vehicle. If no second vehicle is to be tested, depression of the carriage return key makes the program skip to the "Temperature" question.

That temperature is entered manually at this point as is wind speed and direction. Equipment is being built to provide this information automatically from the Sound Pad. There will also be the addition of some logic in the computer to monitor weather conditions during the test whereby the computer can abort a test due to wind gusts, etc. The time is then entered by the computer, and the test sequence starts as soon as the first truck passes over the first reed switch.

The output sheet shown in Figure 10 contains the vehicle and test description information that was entered on the input sheet as well as the test number assigned by the computer. The temperature, wind speed, and time are also printed. The summary information printed in the middle of the page indicates the center frequency of each one-third octave band. Data for the left and right sides of the vehicle are shown under "Left Peak" and "Right Peak," respectively. Under "Level" are the arithmetically averaged maximum levels that occurred at the points shown under the columns labeled "Feet". A peak and the position at which it occurred is given for each of the one-third octaves between 100 Hz and 12.5KHz for both sides of the vehicle. The bottom line is the overall "A" level. The "Feet" preceded by a plus sign indicate positions beyond microphone centerline; whereas, those preceded by minus signs indicate positions before microphone centerline.

In order to simplify the plotting logic, as well as be of more subjective value to the engineer for development work, all the one-third octave data is "A" weighted as it is shown. This is done by "A" weighting the signal before it gets to the one-third octave filters. By using this technique, frequencies that contain problem levels are easily recognized without having to remember the weighting factor for each one-third octave. In the lower left hand portion of the page, the overall "A" weighted peaks that occurred for each pass are summarized. In the center of the page are the SAE averages. These are based on the averaging technique called out in SAE J-366a, whereby the levels from the two highest runs within 2 dB(A) of each other are averaged. The upper figures are for the right side of the vehicle, and the lower ones are for the left as labeled.

The remainder of the output sheet deals with the plot. The left side of the sheet is for the left side of the vehicle; the right side of the sheet is for the right side of the vehicle. Data from 60 feet before microphone centerline to 100 feet beyond microphone centerline is all that is plotted. In order to avoid confusing the plot with unnecessary information, only significant data is plotted. This selection is made by the computer and is based on the SAE average, i e., plotting reference lines are more than 15 and less than 20 dB(A) below the SAE average and will always be a multiple of five. All data below this level is ignored since it does not affect the overall level. This data threshold is listed near the top on the left hand side of the sheet. Here also, the fact that the third octaves are "A" weighted is pointed out, and the value of each vertical major division is enumerated. In the case of the example shown in Figure 10, data threshold was 65 dB and each major division was 5 dB. This means that the line directly under each one-third octave center frequency represents 65 dB for that one-third octave. Looking at the overall "A" level, the line directly under "A" is 65 dB(A). Each major division above that represents an additional 5 dB. Following the trace, it is noted that the peak level on the left side as provided by the plot corresponds with the 81.5 dB(A) shown in the summary of the peak. A separate plot is then made for each of the one-third octaves having data above 65 dB(A). Once the trace is started from the left, the pen is not lifted until the center of the sheet is reached for left side data. If there will be information plotted for the right side, the trace is started at the center of the page. This technique provides trace identification, but it must be remembered that the actual level at those points is likely to be below the data threshold level. It is also important to remember that all of the plotted data as well as the summarized information is the average of data from several passes.

This plotting method effectively presents the three

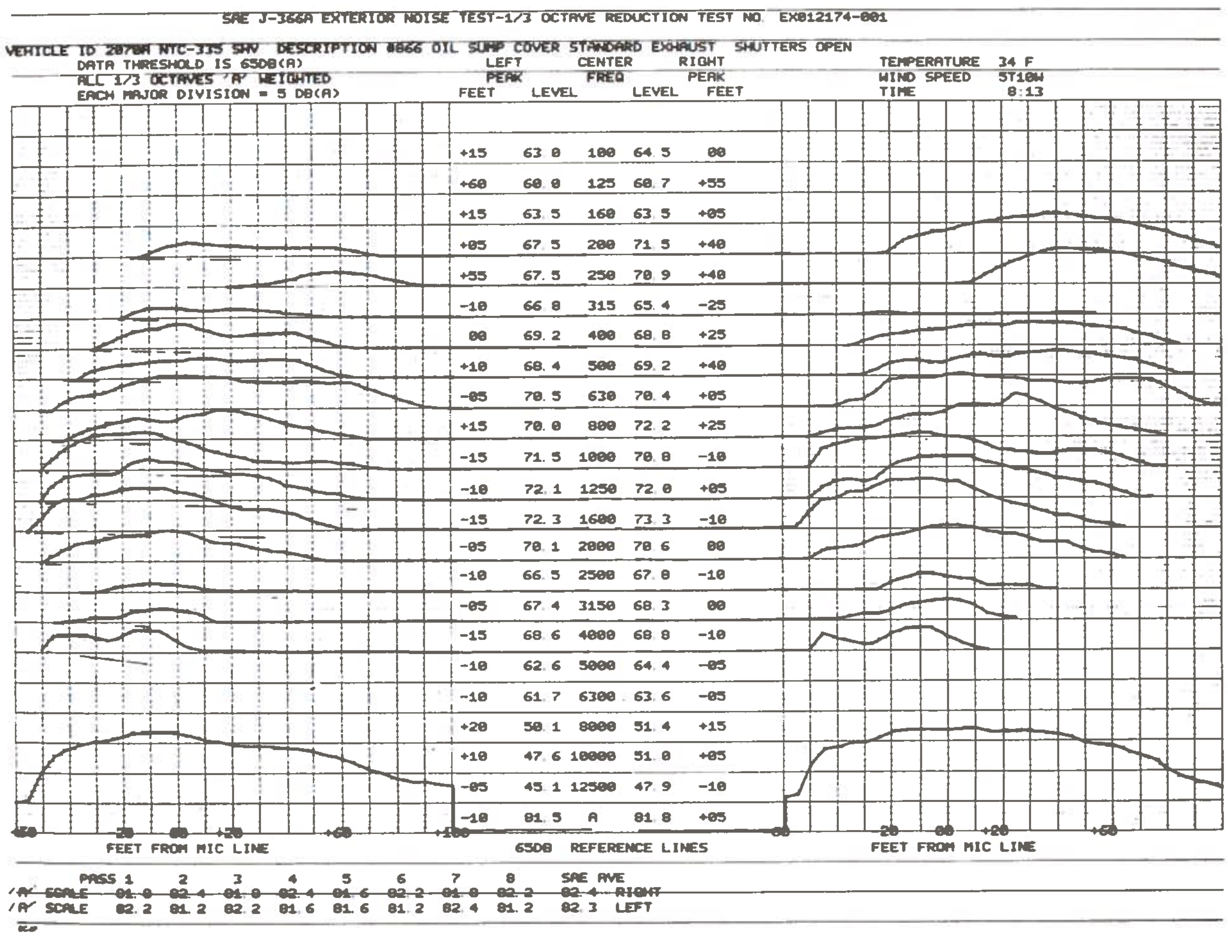


Fig. 10 - Computer analysis of J-366a drive-by noise test

dimensions of level, frequency, and truck position. A three dimensional plot can be visualized by imagining that each of the one-third octave plots are rotated 90 degrees. X represents position; Y represents frequency; and, Z represents level Several other methods, including the isometric plot used for speech therapy, were considered, but the selected method appeared to be best suited for this application.

By the time a driver returns to the shop with the vehicle, the engineer has the summarized data in his hands and is ready to initiate the next development step without delay. This avoids having several back-up vehicles to work with as data is reduced by some slower method. Since most development work is done with hard-to-come-by prototype vehicles, this is a distinct advantage.

APPENDIX B

EXTERIOR SOUND LEVEL FOR HEAVY TRUCKS AND BUSES

EXTERIOR SOUND LEVEL FOR HEAVY TRUCKS AND BUSES—SAE J366b

SAE Standard

Report of Vehicle Sound Level Committee approved July 1969 and last revised April 1973.

1. Introduction—This SAE Standard establishes the test procedure, environment, and instrumentation for determining the maximum exterior sound level for highway motor trucks, truck tractors, and buses. The Appendix contains the recommendations of SAE for maximum sound level.

2. Instrumentation—The following instrumentation shall be used, where applicable, for the measurement required:

2.1 A sound level meter which meets the Type 1 requirements of ANSI S1.4-1971, Specification for Sound Level Meters.

2.1.1 As an alternative to making direct measurements using a sound level meter, a microphone or sound level meter may be used with a magnetic tape recorder and/or a graphic level recorder or indicating meter, providing the system meets the requirements of SAE J184.

2.2 A sound level calibrator (see paragraph 5.2.3).

2.3 An engine-speed tachometer (see paragraph 5.1.1).

3. Test Site

3.1 A suitable test site shall consist of a level open space free of large reflecting surfaces, such as parked vehicles, signboards, buildings, or hillsides, located within 100 ft (30 m) of either the vehicle path or the microphone. See Fig. 1.

3.2 The microphone shall be located 50 ft (15 m) from the centerline of the vehicle path and 4 ft (1.2 m) above the ground plane. The normal to the vehicle path from the microphone shall establish the microphone point on the vehicle path.

3.3 An acceleration point shall be established on the vehicle path 50 ft (15 m) before the microphone point.

3.4 An end point shall be established on the vehicle path 100 ft (30 m) from the acceleration point and 50 ft (15 m) from the microphone point.

3.5 The end zone is the last 40 ft (12 m) of vehicle path prior to the end point.

3.6 The measurement area shall be the triangular area formed by the acceleration point, the end point, and the microphone location.

3.7 The reference point on the vehicle, to indicate when the vehicle is at any of the points on the vehicle path, shall be the front of the vehicle except as follows:

3.7.1 If the horizontal distance from the front of the vehicle to the exhaust outlet is more than 200 in (5080 mm), tests shall be run using both the front and rear of the vehicle as reference points.

3.7.2 If the engine is located rearward to the center of the chassis, the rear of the vehicle shall be used as the reference point.

3.8 During measurement, the surface of the ground within the measurement area shall be free from powdery snow, long grass, loose soil, and ashes.

3.9 Because bystanders have an appreciable influence on meter response when they are in the vicinity of the vehicle or microphone, not more than one person, other than the observer reading the meter, shall be within 50 ft (15 m) of the vehicle path or instrument, and that person shall be directly behind the observer reading the meter, on a line through the microphone and the observer.

3.10 The ambient sound level (including wind effects) coming from sources other than the vehicle being measured shall be at least 10 dB(A) lower than the level of the tested vehicle.

3.11 The vehicle path shall be relatively smooth, dry concrete or asphalt, free of extraneous material such as gravel.

4. Procedure

4.1 Vehicle Operation—Full throttle acceleration and closed throttle deceleration tests are to be used. A beginning engine speed and proper gear ratio must be determined for use during measurements.

4.1.1 Select the highest rear axle and/or transmission gear ("highest gear" is used in the usual sense; it is synonymous to the lowest numerical ratio) and an initial vehicle speed such that at wide-open throttle the vehicle will accelerate from the acceleration point:

(a) Starting at no more than two-thirds (66%) of maximum rated or of governed engine speed.

(b) Reaching maximum rated or governed engine speed within the end zone.

(c) Without exceeding 35 mph (56 km/h) before reaching the end point.

4.1.1.1 Should maximum rated or governed rpm be attained before reaching the end zone, decrease the approach rpm in 100 rpm increments until maximum rated or governed rpm is attained within the end zone.

4.1.1.2 Should maximum rated or governed rpm not be attained until beyond the end zone, select the next lower gear until maximum rated or governed rpm is attained within the end zone.

4.1.1.3 Should the lowest gear still result in reaching maximum rated or governed rpm beyond the permissible end zone, unload the vehicle and/or increase the approach rpm in 100 rpm increments until the maximum rated or governed rpm is reached within the end zone.

4.1.2 For the acceleration test, approach the acceleration point using the engine speed and gear ratio selected in paragraph 4.1.1 and at the acceleration point rapidly establish wide-open throttle. The vehicle reference shall be as indicated in paragraph 3.7. Acceleration shall continue until maximum rated or governed engine speed is reached.

4.1.3 Wheel slip which affects maximum sound level must be avoided.

4.1.4 For the deceleration test, approach the microphone point at maximum rated or governed engine speed in the gear selected for the acceleration test. At the microphone point, close the throttle and allow the vehicle to decelerate to one-half of maximum rated or of governed engine speed. The vehicle reference shall be as indicated in paragraph 3.7. If the vehicle is equipped with an exhaust brake, this deceleration test is to be repeated with the brake full on immediately following closing of the throttle.

4.2 Measurements

4.2.1 The meter shall be set for "fast" response and the A-weighted network.

4.2.2 The meter shall be observed during the period while the vehicle is accelerating or decelerating. The applicable reading shall be the highest sound level obtained for the run. The observer is cautioned to rerun the test if unrelated peaks should occur due to extraneous ambient noises. Readings shall be taken on both sides of the vehicle.

4.2.3 The sound-level for each side of the vehicle shall be the average of the two highest readings which are within 2 dB of each other. Report the sound level for the side of the vehicle with the highest readings.

5. General Comments—Measurements shall be made only when wind velocity is below 12 mph (19 km/h).

5.1 It is strongly recommended that technically trained personnel select the equipment and that tests are conducted only by qualified persons trained in the current techniques of sound measurement.

5.2 Proper usage of all test instrumentation is essential to obtain valid measurements. Operating manuals or other literature furnished by the instrument manufacturer should be referred to for both recommended operation of the instrument and precautions to be observed. Specific items to be considered are:

5.2.1 The effects of ambient weather conditions on the performance

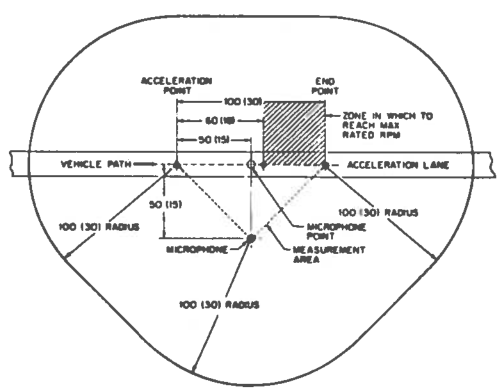


FIG. 1—MINIMUM UNIDIRECTIONAL TEST SITE (SEE PARAGRAPH 3.1)

APPENDIX C

CONSTANT SPEED DRIVE-BY TEST PROCEDURE

The constant speed drive-by test is similar to the regular drive-by test per SAE J-366b Standard Practice except the governed speed is controlled. A gear ratio is selected to maintain vehicle speed less than 35 mph (56.3 Kmph) at engine revolution rates representing 80, 90 and 100 percent of maximum rated governed value.

The instrumentation and procedures are same as for SAE J366b drive-by test described in Appendix B. The test data acquisition and analysis was carried out in accordance with the method presented in Appendix A.

APPENDIX D

IDLE - MAX. SPEED - IDLE NOISE TEST PROCEDURE

This is a stationary vehicle test for determining exterior sound level of heavy trucks or buses, and is called Idle-Maximum Governed Speed - Idle Test (IMI). The test consists of a rapid acceleration of the engine at wide open throttle (WOT) conditions from idle speed up to the maximum governed speed and then a rapid deceleration to idle speed at the minimum throttle conditions. Rapid application of the throttle to the maximum fuel and then to minimum fuel condition is required. The transmission should be in neutral position. The instrumentation and procedures other than the operating mode are same as prescribed for SAE J-366b drive-by tests in Appendix B.

The assumption for using this test is that at low vehicle speeds (less than 35 mph (56.3 Kmph)) the tire and other vehicle component noise is less than the engine related noise sources as maximum engine noise is generated during the acceleration of the engine against its own inertia.

A comparison was carried out with IMI vs. SAE J-366b data. The comparison followed the trend previously established from other data sources.

APPENDIX E

BMCS REGULATION

DEPARTMENT OF TRANSPORTATION, FEDERAL HIGHWAY ADMINISTRATION VEHICLE INTERIOR NOISE LEVELS

(Title 49, Code of Federal Regulations, Chapter III, Subchapter B, Part 393.94, 38 FR 30880, November 8, 1973; Amended by 40 FR 32335, August 1, 1975)

Title 49—Transportation

CHAPTER III—FEDERAL HIGHWAY ADMINISTRATION, DEPARTMENT OF TRANSPORTATION

SUBCHAPTER B—MOTOR CARRIER SAFETY REGULATIONS

[Docket No. MC-22; Notice No. 73-27]

PART 393—PARTS AND ACCESSORIES NECESSARY FOR SAFE OPERATION

Vehicle Interior Noise Levels

§ 393.94 Vehicle interior noise levels.

(a) *Application of the rule in this section.* Except as provided in paragraph (d) of this section, this section applies to all motor vehicles manufactured on and after October 1, 1974. On and after April 1, 1975, this section applies to all motor vehicles manufactured before October 1, 1974.

[40 FR 32335, August 1, 1975]

(b) *General rule.* The interior sound level at the driver's seating position of a motor vehicle must not exceed 90 dB(A) when measured in accordance with paragraph (c) of this section.

(c) *Test procedure.*[1] (1) Park the vehicle at a location so that no large reflecting surfaces, such as other vehicles, signboards, buildings, or hills, are within 50 feet of the driver's seating position.

(2) Close all vehicle doors, windows, and vents. Turn off all power-operated accessories.

(3) Place the driver in his normal seated position at the vehicle's controls. Evacuate all occupants except the driver and the person conducting the test.

(4) Use a sound level meter which meets the requirements of the American National Standards Institute Standard ANSI S1.4-1971 Specification for Sound Level Meters, for Type 2 Meters. Set the meter to the A-weighting network, "fast" meter response.

(5) Locate the microphone, oriented vertically upward, 6 inches to the right of, in the same plane as, and directly in line with, the driver's right ear.

(6) With the vehicle's transmission in neutral gear, accelerate its engine to either its maximum governed engine speed, if it is equipped with an engine governor, or its speed at its maximum rated horsepower, if it is not equipped with an engine governor. Stabilize the engine at that speed.

(7) Observe the A-weighted sound level reading on the meter for the stabilized engine speed condition. Record that reading, if the reading has not been influenced by extraneous noise sources such as motor vehicles operating on adjacent roadways.

(8) Return the vehicle's engine speed to idle and repeat the procedures specified in paragraphs (c)(6) and (c)(7) of this section until two maximum sound levels within 2 dB of each other are recorded. Numerically average those two maximum sound level readings.

(9) The average obtained in accordance with paragraph (c)(8) of this section is the vehicle's interior sound level at the driver's seating position for the purpose of determining whether the vehicle conforms to the rule in paragraph (b) of this section. However, a 2 dB tolerance over the sound level limitation specified in that paragraph is permitted to allow for variations in test conditions and variations in the capabilities of meters.

(d) Vehicles manufactured before October 1, 1974, and operated wholly within the State of Hawaii, need not comply with this section until April 1, 1976.

[40 FR 32335, August 1, 1975]

[FR Doc.73-23768 Filed 11-7-73;8:45 am]

[1] Standards of the American National Standards Institute are published by the American National Standards Institute. Information and copies may be obtained by writing to the Institute at 1430 Broadway, New York, N.Y. 10018.

APPENDIX F

SOUND LEVEL FOR TRUCK CAB INTERIOR—SAE J336a

SAE Recommended Practice

Report of Vehicle Sound Level Committee approved June 1968 and last revised July 1973.

1. Introduction—This SAE Recommended Practice describes the equipment and procedure for determining the maximum truck cab interior sound level. This practice applies to motor trucks and truck-tractors and does not include construction and industrial machinery. The appendix contains SAE recommended design criteria for new vehicles.

2. Instrumentation—The following instrumentation shall be used, where applicable, for the measurement required:

2.1 A sound level meter which meets the Type 1 requirements of ANSI S1.4-1971, Specification for Sound Level Meters.

2.2 A set of octave bandpass filters which meet the Class II requirements of ANSI S1.11-1966, Specification for Octave, Half-Octave and Third-Octave Band Filter Sets.

2.2.1 As an alternative to making direct measurements with a sound level meter and octave band filter set, a microphone or sound level meter may be used with a magnetic tape recorder and/or a graphic level recorder or indicating meter, provided that the system used meets the requirements of SAE J184.

2.3 A sound level calibrator (see paragraph 4.2.3).

2.4 An engine-speed tachometer.

3. Test Procedure—The following procedure is to be used for the purpose of this SAE Recommended Practice.

3.1 Establish a seat reference point at the intersection of the tangent lines to the predominant surfaces of the undeflected cushion and backrest at the lateral center of the seat (or intended operator location). Adjust the seat to the midpoint of its horizontal and vertical travel. Locate the microphone, oriented vertically upward, at a point 29 in (740 mm) vertically above the seat reference point and 10 in (250 mm) laterally to the right (to the left for right-hand drive vehicles) of the seat reference point.

Position the driver so that his ear is reasonably aligned with, and approximately 6 in (150 mm) laterally from, the microphone. Seat adjustment may be made to meet this provision.

3.2 Sound level tests may be conducted with or without a trailer or body on the vehicle.

3.3 On vehicles equipped with radiator shutters, the shutter position causing the maximum sound level should be determined and the tests conducted with the shutters in such position.

3.4 Vehicle windows and vents are to be in the fully closed position with all accessories "off."

3.5 The tests are to be conducted on smooth, dry concrete or asphalt road surfaces. No large sound reflecting surfaces should be within 50 ft (15 m) of the test vehicle. Wind speed should not exceed 15 mph (24 km/h).

3.6 Select a transmission and/or axle gear ratio so that approximately 50 mph (80 km/h) is obtained at rated engine speed.

3.7 Obtain the maximum band pressure level reading in each octave band during acceleration in the selected gear ratio of paragraph 3.6 at wide-open throttle from a beginning engine speed of one-half rated engine speed up to rated engine speed. The meter shall be set for "fast" response for these measurements and a minimum of four test runs shall be made.

3.7.1 If a magnetic tape recording system is used, make recordings during at least four test runs. Obtain a band pressure level measurement for each octave band for each test recording. Set the level indicating device for "fast" response or equivalent for these measurements.

3.8 The applicable reading for each band shall be the highest band pressure level observed. The band pressure levels reported shall be the average of the two highest readings within 2 dB of each other. The observer is cautioned to rerun the test if unrelated peaks should occur due to extraneous ambient noises.

4. General Comments

4.1 It is strongly recommended that technically qualified personnel select the equipment and that tests are conducted only by qualified persons trained in the current techniques of sound measurement.

4.2 Proper use of all test instrumentation is essential to obtain valid measurements. Operating manuals or other literature furnished by the instrument manufacturer should be referred to for both recommended operation of the instrument and precautions to be observed. Specific items to be considered are:

4.2.1 The effects of ambient weather conditions on the performance of all instruments (that is, temperature, humidity, and barometric pressure).

4.2.2 Proper signal levels, terminating impedances, and cable lengths on multi-instrument measurement systems.

4.2.3 Proper acoustical calibration procedure, to include the influence of extension cables, etc. Field calibration shall be made immediately before and after each test sequence. Internal calibration means is acceptable for field use, provided that external calibration is accomplished immediately before or after field use.

If a magnetic tape recorder is used, record a calibration signal of known acoustic level immediately prior to, or following, each sequence of test recordings.

4.2.3 For analysis of the recordings, use the calibration signal to establish playback gain and thus calibrate the analysis system.

4.3 Vehicles used for tests must not be operated in a manner such that the break-in procedure specified by the manufacturer is violated.

5. References—Suggested reference material is as follows:

5.1 ANSI S1.1-1960, Acoustical Terminology

5.2 ANSI S1.2-1962, Physical Measurement of Sound

5.3 ANSI S1.11-1966, Octave, Half-Octave, and Third-Octave Band Filter Sets

5.4 ANSI S1.4-1971, Specification for Sound Level Meters

5.5 SAE J184, Qualifying a Sound Data Acquisition System

Applications for copies of these documents should be addressed to the American National Standards Institute, Inc., 1430 Broadway, New York, New York 10018; or, the Society of Automotive Engineers Inc., Two Pennsylvania Plaza, New York, New York 10001.

APPENDIX
DESIGN CRITERIA

The SAE recommends that the octave band pressure levels listed below be considered during the development of new vehicles:

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

Trucks meet the design criteria if the sum of reported band pressure levels does not exceed the sum of the criteria band pressure levels, provided that no reported band pressure level exceeds the corresponding criteria band level by more than 3 dB. (See paragraph 3.8.)

APPENDIX G

EXHAUST BACKPRESSURE MEASUREMENT PROCEDURE

Exhaust flow restriction is very important for efficient engine operation, and maximum limit is established by the engine manufacturers. In the Retrofit Program exhaust back-pressure was considered essential part of the evaluation of the commercially available noise reducing exhaust mufflers.

Backpressure is normally measured in the exhaust pipe as close to the manifold as possible. The ideal location for measurement is suggested to be in a straight section of the exhaust pipe, at least two pipe-diameters away from a bend or other discontinuity. Such ideal location was not available on the development trucks due to short exhaust pipe and immediate bends. As a compromise, a backpressure tap was placed in the first bend after the manifold normal to the plane of the bend. This backpressure tap was a tube-fitting, and it was carefully installed in the exhaust pipe so that it did not protrude beyond the inner wall. A U-tube manometer, filled with mercury was connected to the tap with flexible tubing.

The procedure for measuring backpressure requires operating the truck in the same gear as used for sound runs. Full throttle is established and vehicle is operated until the engine speed is stabilized near maximum, no load. The vehicle brakes are then applied to load the engine. As the engine speed is forced down due to braking, the mercury in the U-tube manometer rises. Maximum reading on the manometer thus gives the exhaust backpressure. This reading is compared with engine manufacturer's specifications.

APPENDIX H

INTAKE RESTRICTION MEASUREMENT PROCEDURE

The procedure for measuring intake restriction is similar to that of the exhaust backpressure. The ideal location for measurement is near the intake manifold (or blower inlet), at least two pipe diameters away from a bend or other obstructions. A U-tube water manometer is connected at the selected location on the intake with flexible tubing. The engine is operated at full governed speed, no load.

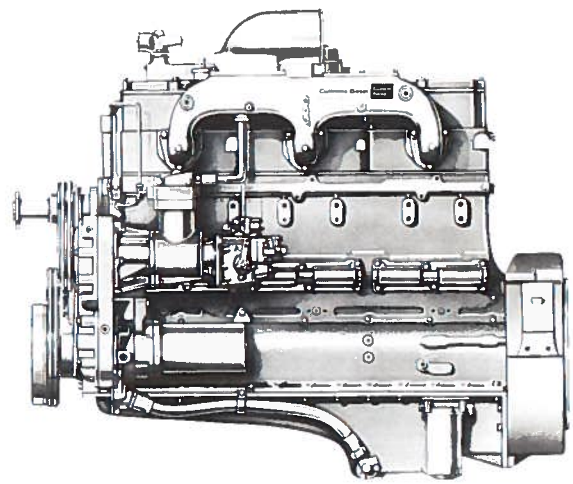
Water in the manometer starts rising, and maximum reading on the manometer gives the intake restriction in inches of water.

The allowable intake restriction is only a fraction of the exhaust backpressure since it is limited by the atmospheric pressure. Like backpressure, intake restriction specification is established by the engine manufacturer, and measurements must be compared with this specification.

APPENDIX I

NHC-250 (12248)

TYPE............................ 6 cyl., Valve-in-Head, 4 Cycle
BORE AND STROKE (in.).............................5.5 x 6
DISPLACEMENT (cu. in.)................................855
COMPRESSION RATIO.................................15.8:1
GOVERNED SPEED (RPM)...............................2100
GROSS HP @ RPM..............................250 @ 2100
*NET HP @ RPM...............................231 @ 2100
TAXABLE H.P..72.6
GROSS TORQUE Lbs/Ft @ RPM.................658 @ 1500
*NET TORQUE Lbs/Ft @ RPM..................585 @ 1500
AIR FLOW @ 2100 RPM (CFM)..........................460
WEIGHT (L/starter, alt., compr., fan & clutch-dry (lbs.)...2370



* Net figures are for engine installed with air cleaner, fan, alternator (under load), exhaust and air compressor (no load).

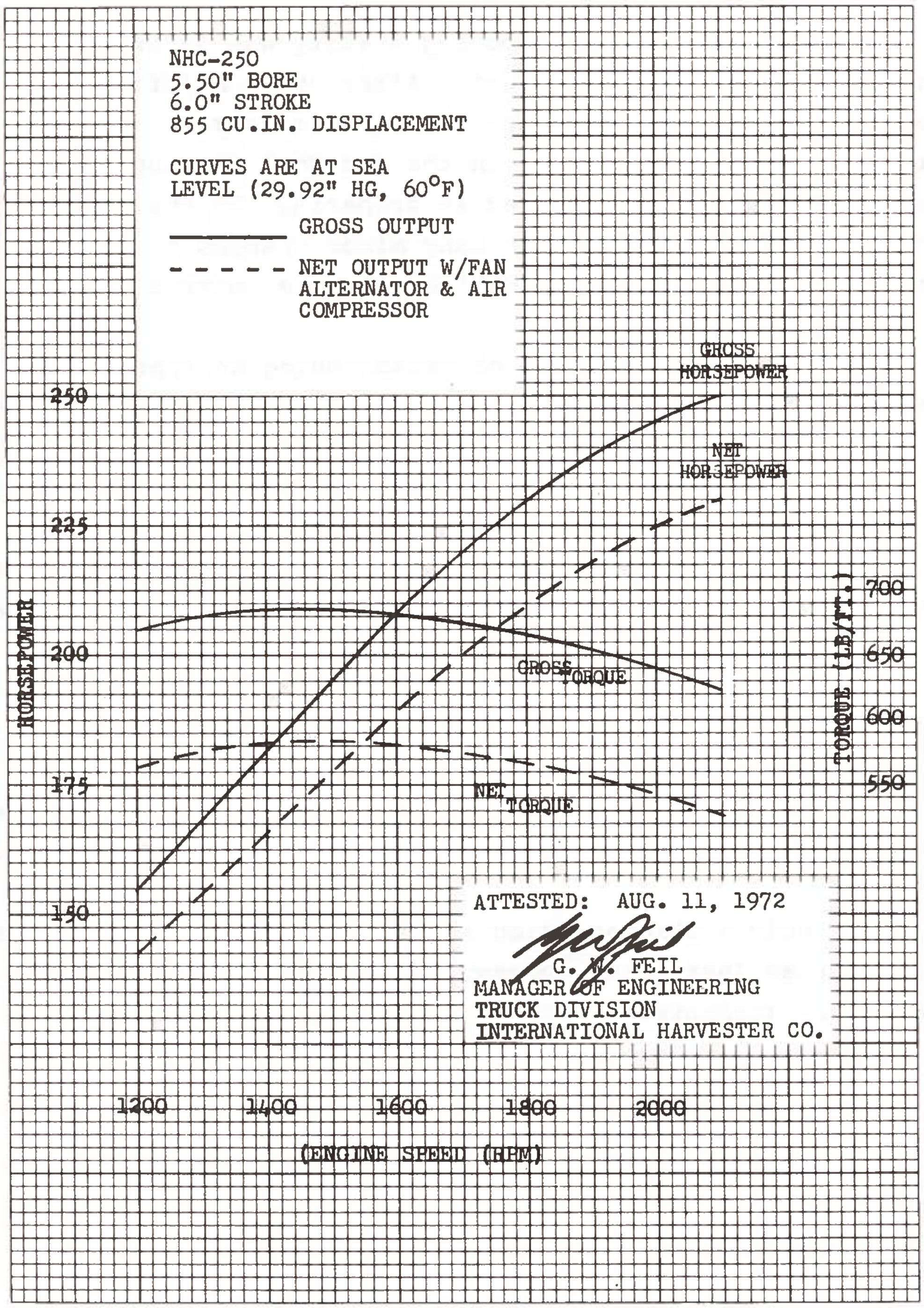
See chart on page 24-27 for Optional Equipment and accessory H.P. demands.

MODEL APPLICATION

STANDARD EQUIPMENT	2070A FLEETSTAR	CO TRANSTAR	4300 TRANSTAR	5000 PAYSTAR
AIR COMPRESSOR	——	12 Cu. Ft. — BW — Gear Driven		
AIR CLEANER	——	14" Cyclopac w/Vacuator	16 x 16" Donaclone w/Vacuator and Air Restriction Indicator	15 x 16" Donaldson Dry Type w/Pre-Cleaner and Vacuator
AIR INTAKE	——	Vertical Stack	Frontal	Lt. Side Hood
ALTERNATOR	——	12 Volt, 65 Amp, SI-Type		
BATTERIES	——	(4) 6 Volt, 150 Amp-Hour		
COLD START	——	None		
WATER FILTER	——	IH Spin-On Type		
POWER STEERING PUMP	——	Gear Driven		

NHC-250 (12248)

PERFORMANCE CURVES



APPENDIX J

AIR FLOW MEASUREMENT PROCEDURE

The determination of cooling ability was an extremely important part of this project. After every modification, cooling was determined before noise was measured. When making a cooling evaluation in the Hot Room (Appendix L), nearly a full day is required in preparing the chassis and accumulating the data. With many minor changes to be made, cooling runs after every modification were impractical.

As an alternate method of establishing an approximate cooling level, the air flow through the radiator was measured using a flow duct. This duct was a plywood structure of rectangular cross-section which seals to the front of the truck as shown in Figure J-1. It was constructed as a crude nozzle with a converging-diverging section. Air flow was determined by measuring the static pressure at the throat of the nozzle.

Since the nozzle was never calibrated, only relative measurements were taken. In spite of its rather crude construction, it was found that cooling could be predicted within about $\pm$ 2^{o} F when evaluated in the Hot Room. This was considered satisfactory for the purpose of Retrofit Program.

The only instrumentation required with this test facility was a Meriam Instrument Company Model 40G4 inclined tube manometer, graduated in .254mm (0.01 inches) of water.

Figure J-1 Air Flow Duct.

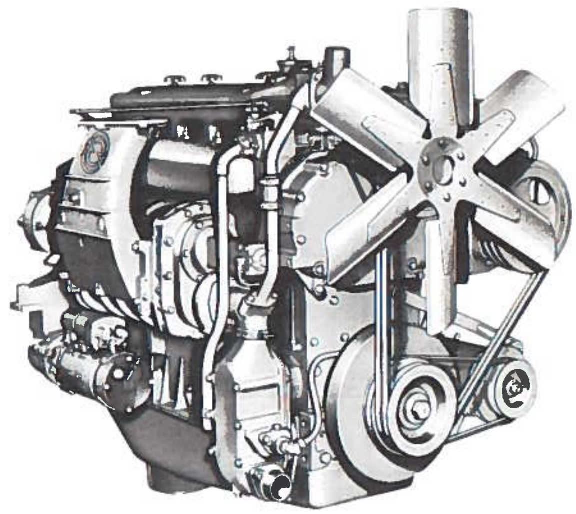
APPENDIX K

6-71 N-65 INJECTORS (12291)

TYPE........................6 cyl., Overhead Valve, 2 Cycle
BORE AND STROKE (in.).......................4.25 x 5.0
DISPLACEMENT (cu. in.).......................426
COMPRESSION RATIO.......................18.7:1
GOVERNED SPEED (RPM).......................2100
GROSS HP @ RPM.......................238 @ 2100
*NET HP @ RPM.......................207 @ 2100
TAXABLE H.P.......................43.5
GROSS TORQUE Lbs/Ft @ RPM.......................653 @ 1400
*NET TORQUE Lbs/Ft @ RPM.......................604 @ 1400
AIR FLOW @ RPM (CFM).......................655 @ 2100
WEIGHT (L/starter, alt., compr., fan & clutch-dry)(lbs.)...2020

* Net figures are for engine installed with air cleaner, fan, alternator (under load), exhaust and air compressor (no load).

See chart on page 25-25 for Optional Equipment and accessory H.P. demands.

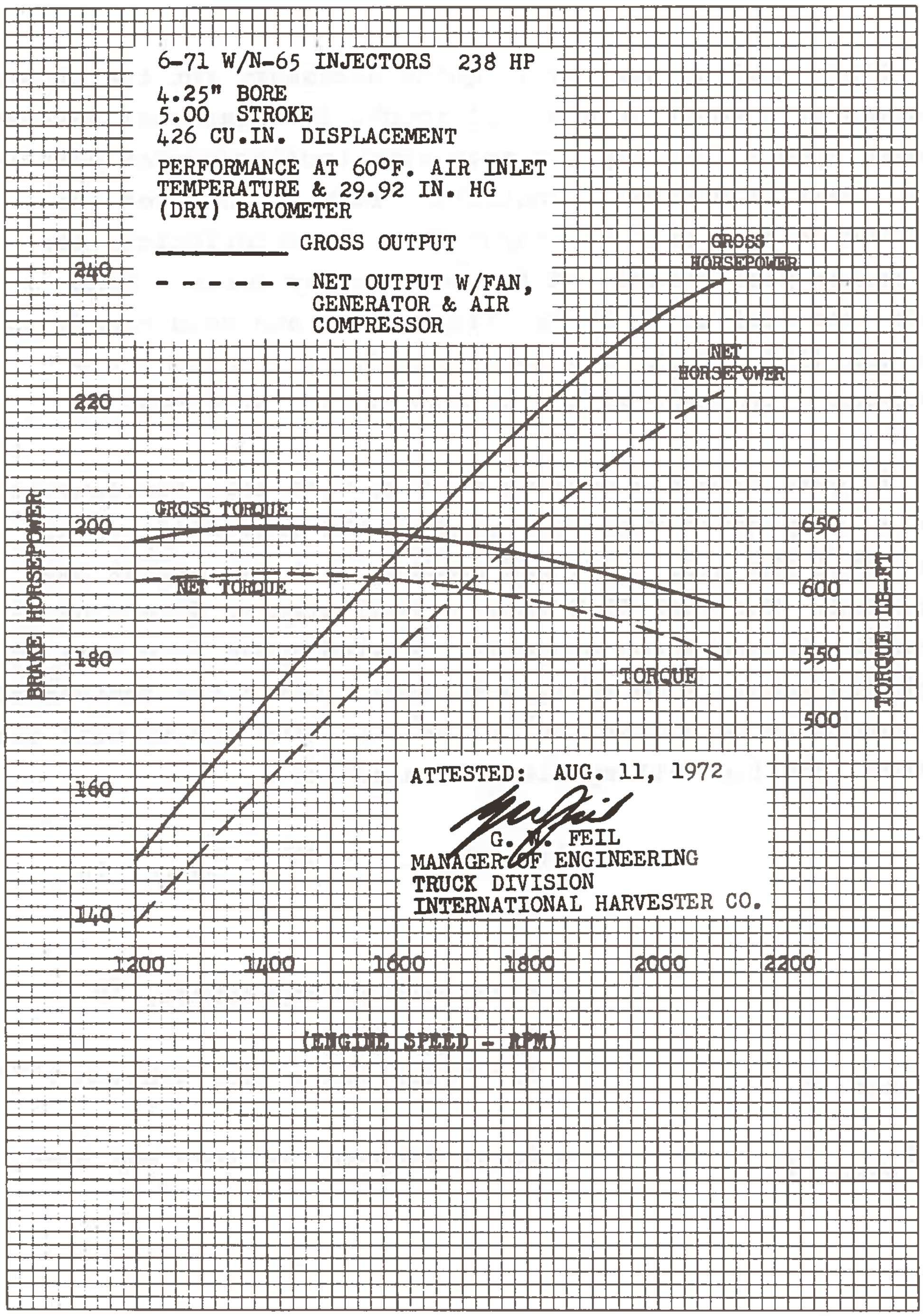


MODEL APPLICATION

STANDARD EQUIPMENT	2070A FLEETSTAR	CO TRANSTAR	4300 TRANSTAR	5000 PAYSTAR
AIR COMPRESSOR	BW — 12 cu. ft. Gear Driven	BW — 12 cu. ft. Belt Driven	BW — 12 cu. ft. Gear Driven	
AIR CLEANER	15 x 16" Canadian Dry Type w/Pre-cleaner and w/Vacuator	14" Cyclopac w/Vacuator	16 x 16" Donaclone w/Vacuator or w/Restriction Indicator	15 x 16" Donaldson Dry Type w/Pre-cleaner and w/Vacuator
AIR INTAKE	Frontal	Vertical Stack	Frontal	Lt. Side Hood
ALTERNATOR	12 Volt, 65 Amp, SI Type			
BATTERIES	(2) 6 Volt, 208 Amp-Hour			
COLD START	None			
WATER FILTER	None			
POWER STEERING PUMP	Gear Driven	Belt Driven	Gear Driven	

6-71 N-65 INJECTORS (12291)

PERFORMANCE CURVES



APPENDIX L

HOT ROOM FACILITY TO DETERMINE COOLING ABILITY

Since cooling ability is quite necessary for the proper operation of a heavy duty diesel truck, International Harvester has developed a facility for measuring cooling system performance. This climatically controlled room can be used for measuring cooling ability, vapor lock characteristics, air conditioner performance and for development tests. Wind speeds (ram air) up to 30 mph (48.3 Kmph) and road speeds up to 70 mph (112.6 Kmph) can be attained. All temperature measurements are made with iron constantan thermocouples.

To determine the cooling ability with this facility, the vehicle is operated with full load at the specified engine speed until the air, water and engine oil temperatures have stabilized. The fuel flow rate is monitored to determine if the engine is operating properly. A wind speed (ram air) of 15 mph (24 Kmph) is normally maintained, while the ambient air temperature is held near 100° F (38° C). The air-to-boil temperature (cooling ability) is determined by:

$$ATB = T_{air\ in} + 212 - T_{water\ in}$$

where:

ATB = Air-to-Boil Temperature, °F

$T_{air\ in}$ = Air Temperature into Radiator, °F

$T_{water\ in}$ = Water Temperature into Radiator, °F

The measured ATB temperature is compared with the engine manufacturer's specifications.

The major instrumentation used with this facility are:

1. Chassis dynamometer, Lukenweld, Inc. No. E-8626-A, tandem axle, 300 HP (223.7 kw) per axle.

2. Ram Air Supply, Class 1, 75 HP (55.93 kw) 109,000 cfm (3086.54M^3/min) maximum (0-30 mph (48 kmph)), New York Blower Company, Tubular-Acousta Foil, Size T-737.

3. Fuel measurement scale -- balance beam type, electrically timed.

4. Honeywell climate controller, steam heat, 135°F (57°C) maximum, humidity control by steam input.

5. 24 channel recording potentiometer, Easterline Angus, Model E1124E.

APPENDIX M

REPORT OF INVENTION

This document was prepared by International Harvester Company, Truck Division Engineering, Fort Wayne, Indiana, under contract DOT-TSC-721. International Harvester Company does not claim any patentable innovations, discoveries, improvements, or inventions as a result of the work performed under this contract, because commercially available source noise reducing components were selected and used on two in-service diesel powered International Harvester trucks to meet the established noise level goals for these trucks.

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