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WR 79-22

LIGHT VEHICLE NOISE: VOLUME IV —

THE EFFECT OF PARTIAL ENGINE ENCLOSURES

ON LIGHT VEHICLE NOISE LEVELS

AND OPERATING TEMPERATURES

For

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Noise Abatement and Control
Arlington, Virginia 22202

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By

Kenneth J. Plotkin
Donald B. Pies

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1.0 INTRODUCTION

Recent measurements conducted on light vehicles indicate that exterior noise due to under-hood sources can be reduced by 3 to 5 dB by enclosing the bottom of the engine compartment.[1] Although the enclosures considered were of flow-through design, i.e., the radiator is not obstructed and the rear of the engine compartment is left open, it is clear that some restriction of cooling air flow may result. A test program has therefore been conducted in which engine enclosures were installed on three light vehicles, and the change to noise level and operating temperatures measured. Temperature measurements were made under stationary idling conditions and at 60 mph cruise. Noise measurements were made with the vehicle stationary, for various steady engine speeds and for a full-throttle kickdown test mode. A quantitative assessment of the reduction in cooling capacity has been made, and design modifications are presented which would restore each vehicle's original cooling performance.

2.0 TEST VEHICLE SELECTION

Pass-by noise measurements of light vehicles indicated that 4-cylinder subcompacts and 8-cylinder light trucks are the noisiest categories of gasoline-engine light vehicles.[2] Three test vehicles were selected from these two categories:

- Plymouth Horizon. This is a 4-cylinder subcompact with transverse engine and front-wheel drive. This configuration is the current state-of-the-art of economy cars, and is expected to gain larger shares of the automobile market.
- Ford Pinto. This is a 4-cylinder, front-engine, rear-wheel-drive subcompact, and represents a conventional layout economy car.
- Chevrolet Van. This is a conventional layout, front-engine, rear-wheel-drive van, powered by a V8. Although this particular model was not found to be substantially noisier than average,[2] the configuration of the engine compartment is similar to noisy models.

Table 1 lists pertinent specifications of the three test vehicles. All vehicles had automatic transmissions.

Table 1

Vehicle Specifications

Vehicle	Engine Type	CID (cu. in.)	BHP @ RPM	Transmission	Cooling Fan
Plymouth Horizon	L4	105	70 @ 5600	3A	14" Electric, Shrouded
Ford Pinto	L4	140	89 @ 4800	3A	16", 4 Blades
Chevrolet Van 20	V8	350	168 @ 3800	3A	7 Blades, Viscous Clutch

3.0 VEHICLE PREPARATION AND INSTRUMENTATION

3.1 Vehicle Preparation

Prior to testing, each vehicle was examined to ensure it was properly tuned, and that the cooling system was filled with a mixture of 44 percent ethylene glycol/ 56 percent water. Engine idle speed was set to manufacturer's specifications.

To ensure that meaningful temperature comparisons could be made, thermostatic controls on the cooling system were disabled. On all three vehicles, the thermostats were replaced with units which were blocked in the fully open position. This provided a fixed cooling system geometry. The viscous drive fan on the Chevrolet was clamped to its shaft so as to run always at pulley speed. This gave a fan speed substantially higher than would occur in normal service, but which was constant for all tests. The Plymouth was tested with the electric fan thermostatically controlled, disabled, and fixed on.

3.2 Instrumentation

Temperatures at various points on the vehicle were recorded on a Honeywell 153 temperature chart recorder, using Type T (copper-constantan) thermocouples. This recorder was set up for six channels and would record the temperatures at an approximate rate of one channel every six seconds. Thermocouples were placed in the following locations:

1. Radiator top tank, in the vicinity of the upper hose connection.
2. Engine oil, attached to the tip of the dipstick.
3. Transmission oil, attached to the tip of the dipstick.
4. Approximately one inch in front of the grill.
5. In the engine compartment, between the rear of the engine block and the firewall.
6. Above the roof of the vehicle, mounted on a wire strut. This provided an ambient measurement to supplement position 4, but which would not be influenced by pavement temperatures or proximity to the radiator.

On the Plymouth, the sixth position was used for part of the test only. For most of the testing, the sixth data channel was used to record whether the thermostatic electric fan was on or off. The duty cycle was thus obtained.

Engine speed was obtained by connecting a frequency-to-voltage converter to the primary side of the ignition system, and displaying the voltage on a Flüke 8000A digital multimeter. The frequency-to-voltage converter was calibrated such that 1000 RPM = 1 volt. Engine speeds were recorded manually on a run log.

Air flow was measured using a Hastings-Raydist B-27 air-flow meter, with a J-3D omnidirectional probe mounted on the grill approximately centered over the engine cooling fan. Figure 1 shows the probe mounting on the Plymouth. Flow data were manually logged.

The on-vehicle instrumentation displays were placed in the back seat of the vehicle, as shown in Figure 2. The test engineer sat in the back, monitoring the instrumentation and maintaining the run log, while the driver operated the vehicle in the required modes. Vehicle speed was read by the driver from the vehicle's speedometer.

Exterior noise measurements were mdde with a GenRad 1933 sound level meter, with a 1-inch ceramic microphone. A-weighting and fast response were selected. Sound level and engine RPM were recorded simultaneously on a Hewlett Packard 7402A two-channel chart recorder, equipped with 17401A medium gain preamplifiers. Acoustic calibration was performed using a Bruel and KjaerrType 4230 calibrator.

4.0 ENCLOSURE DESIGN AND CONSTRUCTION

The enclosures were designed with the following constraints:

- Attach to the front sheet metal or radiator shroud such that air may enter the front of the engine compartment through the radiator only.
- Extend rearward to cover the area under the engine, but leaving an opening for under-hood air to exit.
- Extend up the inner fender wells, leaving only those openings necessary for suspension and steering linkage movement.
- Absorptive material lining the enclosure.

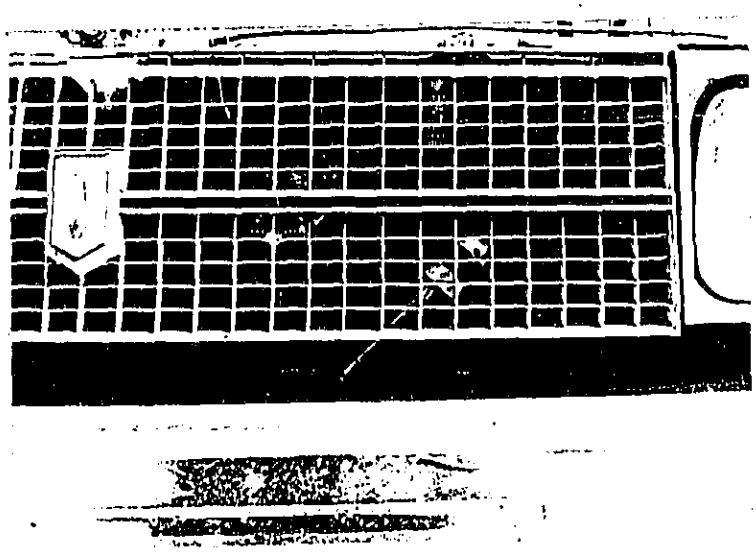
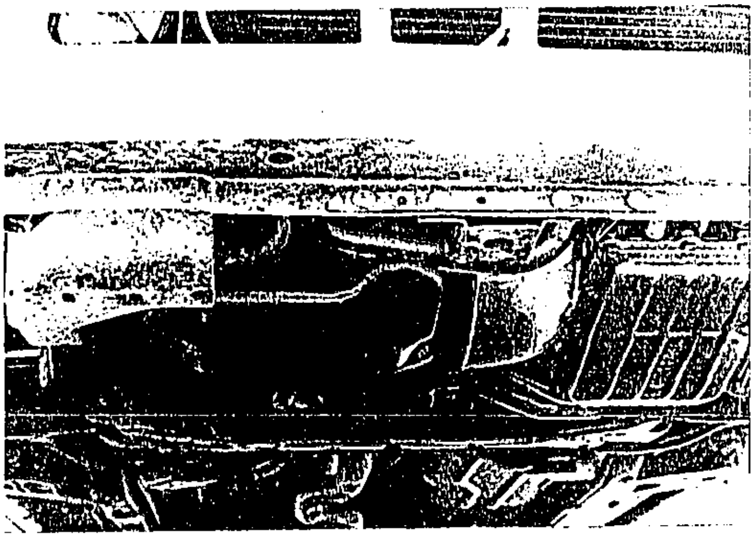


Figure 1. Air Speed Probe.

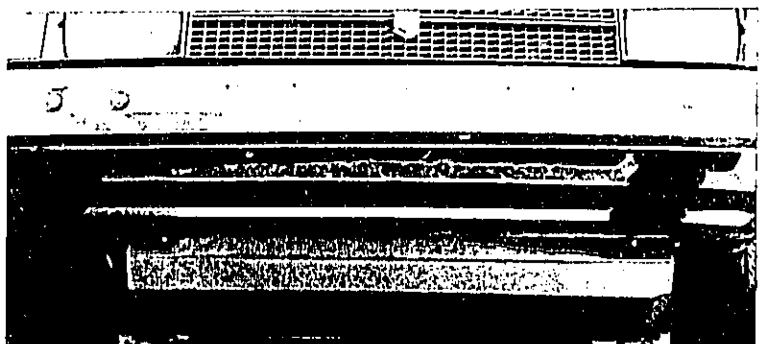
Figure 2. On-Vehicle Data Recording System.

The enclosures were constructed in the most expedient manner possible consistent with structural integrity. Materials used were 0.072-inch aluminum sheet (weight approximately one pound per square foot) and a material consisting of one pound per square foot vinyl with 1/4-inch open-cell foam bonded to it. The basic enclosure was first constructed from aluminum, then lined with the vinyl/foam material, foam side toward the engine. This double layer construction avoided the need to seal all joints in the aluminum structure, but resulted in an enclosure which was twice as heavy as required for acoustical purposes. Total weight of each enclosure here was 25 to 30 pounds; production versions should not weigh more than 15 pounds. Attachment to the vehicle was achieved by bolting to existing holes, using weatherstripping to seal joints. Pieces of vinyl/foam were used to fill irregular areas where fitting sheet metal would have been awkward. These were attached with duct tape.

Figures 3, 4, and 5 show the enclosures as installed on the three vehicles, as well as the same views without the enclosures. The enclosures on the Plymouth and Ford were relatively "clean", with the basic structure consisting of four-sided aluminum tub. The complete enclosure (including irregular vinyl extensions) could be installed and removed in a single piece. Noise reduction of 3 to 5 dB would be expected from these enclosures. The Chevrolet presented a less ideal geometry. The area to be covered was irregular, and a crossmember and the exhaust crossover pipe presented obstacles. The enclosure had to be fabricated in several pieces, and a number of clearance holes and gaps were needed. No more than 3 dB noise reduction would be expected from the enclosure as shown in Figure 5. A production enclosure on this type of vehicle would not be as straightforward as on the other two vehicles.

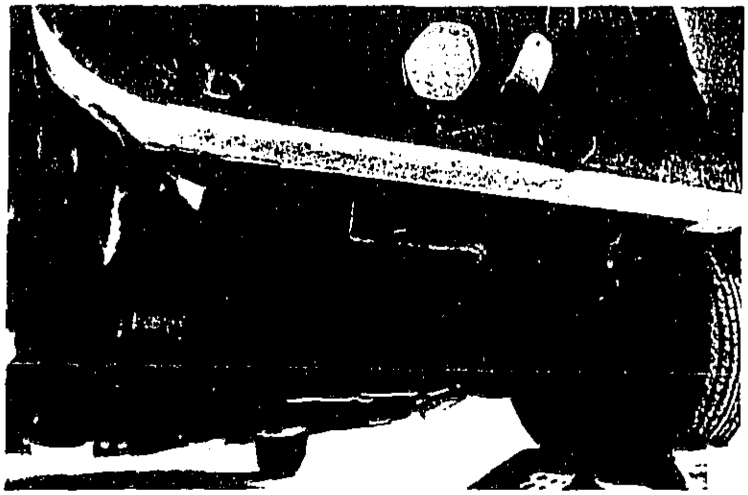


a) Stock

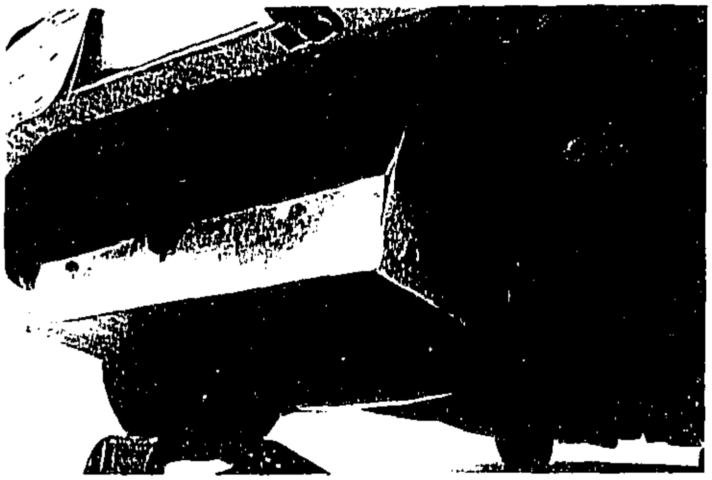


b) With Enclosure

Figure 3. Plymouth Horizon Enclosure.

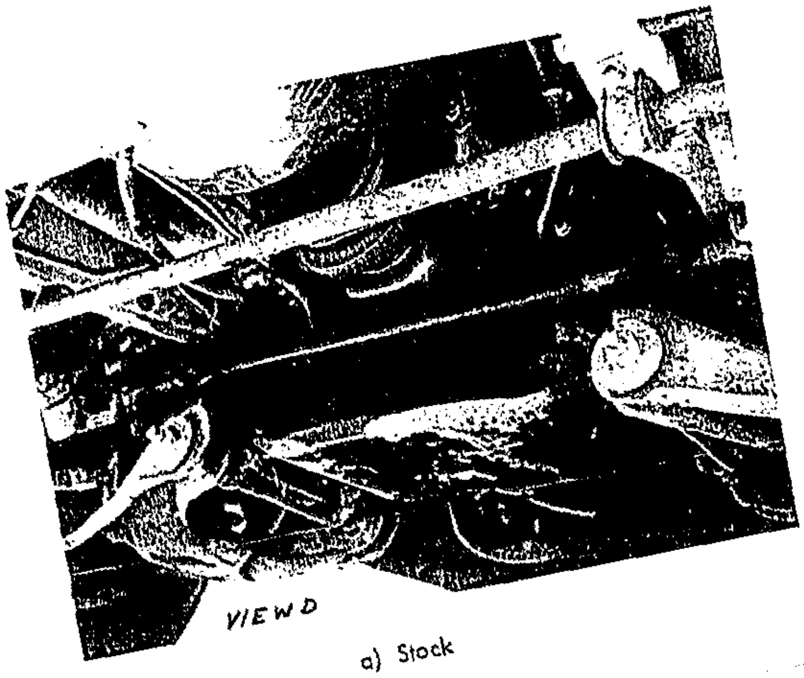


a) Stock



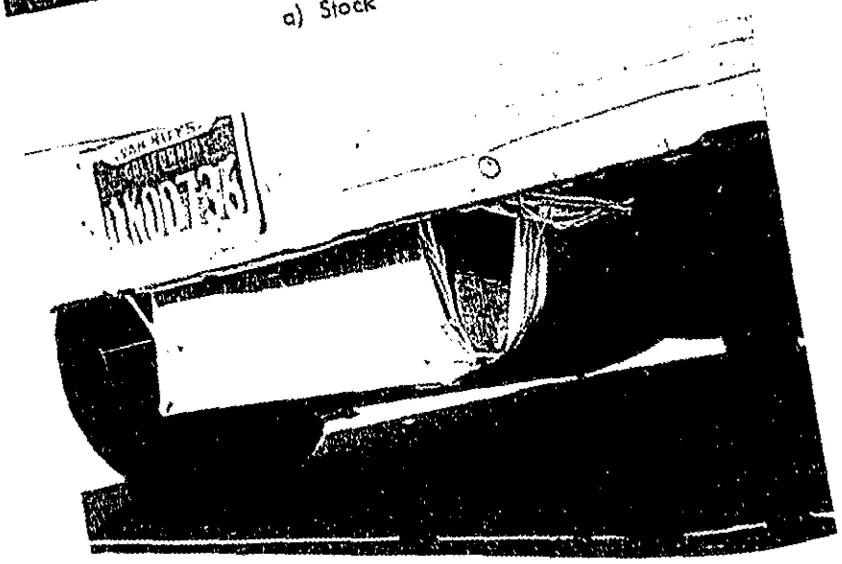
b) With Enclosure

Figure 4. Ford Pinto Enclosure.



VIEW D

a) Stock



VIEW D

b) With Enclosure

Figure 5. Chevrolet Van Enclosure

5.0 TEST PROCEDURES

The following procedure was followed for each vehicle:

1. The enclosure and instrumentation was installed at Wyle's El Segundo, CA, facility.

2. Following installation, the vehicle was started and idled in neutral until stable temperatures were achieved.

3. The vehicle was then driven to Wyle's Norco, CA, facility. This trip is approximately 60 miles, most of which is by freeway.

4. During the freeway part of the drive, a steady 60 mph was maintained. The data log was annotated every 5 to 10 minutes, and at any point where the steady speed was interrupted. A steady period of at least 20 minutes was achieved for all 3 vehicles, during which time temperatures stabilized.

5. Upon exiting the freeway at Corona, CA, the vehicle was parked with the engine idling and transmission in Drive. This was done at a parking lot about 1/4-mile beyond the highway exit, which was the closest safe area available. The vehicle was left idling until temperatures stabilized. This generally took less than 15 minutes.

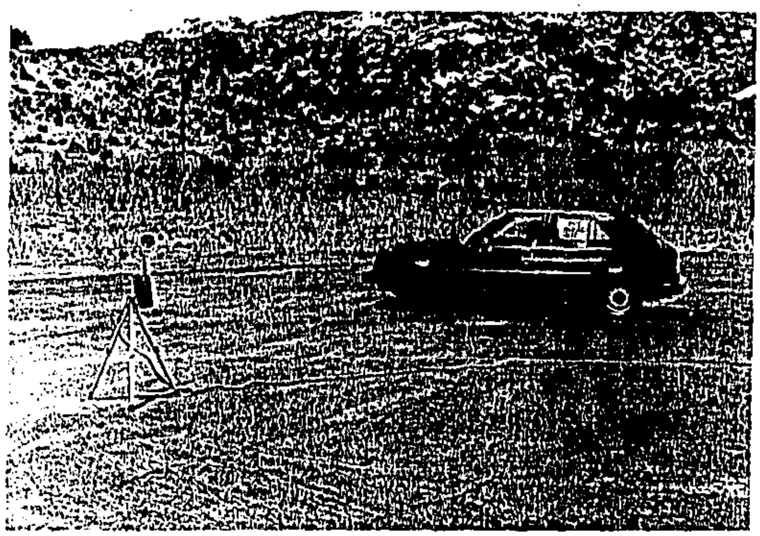
6. The vehicle was then driven to the Wyle-Norco facility, and parked on the circular vehicle noise test pad. Additional idle measurements were made in Drive.

7. Noise tests were then conducted. These consisted of:

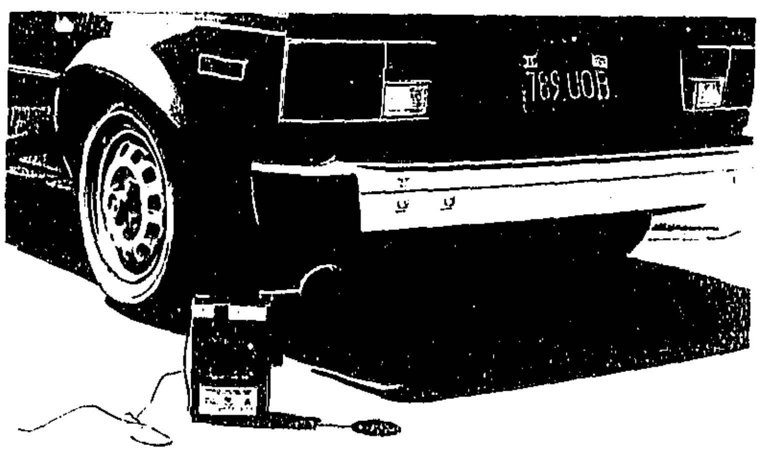
   - Steady engine speeds of 50, 60, 70, 80, and 90 percent of rated speed, transmission in neutral.

   - Maximum throttle kickdown, transmission in neutral. The throttle was released as needed to avoid overspeeding the engine.

The tests were conducted with a microphone 25 feet to the side of the vehicle (left side for Plymouth and Ford, right side for Chevrolet) and even with the front bumper — see Figure 6a. They were repeated with the microphone 20 inches from the exhaust pipe outlet, at an angle of 45° to its axis, and at the same



a) 25-Foot Sideline Microphone



b) Exhaust Microphone

Figure 6. Microphone Position.

height as the outlet — see Figure 6b. This exhaust measurement was made to ensure that exhaust noise did not dominate the 25-foot measurement. Exhaust noise was found to be non-negligible on the left side of the Chevrolet (the side with the tailpipe), so that the 25-foot microphone was placed on the right side for that vehicle.

8. The enclosure was then removed and the noise tests repeated for the 25-foot microphone position.

9. Idle temperature test was repeated.

10. Steady 60 mph cruise temperature test was repeated on the return trip to El Segundo.

6.0 TEST RESULTS

6.1 Cooling System Performance

Tables 2, 3, and 4 show the results of the temperature measurements for the three vehicles. Part "a" of each table shows the temperatures recorded at each thermocouple position plus air flow data and ambient temperatures. Part "b" of each table shows the fluid and under-hood temperatures which would occur for a 100°F ambient. These were obtained by adding 100° minus the test ambient to the recorded test temperatures. Also shown in the tables are the calculated air-to-boil (ATB) temperatures. This is defined as:

ATB = ambient temperature plus coolant boil temperature
minus measured coolant temperature.

This is essentially the ambient temperature at which the cooling system would boil. Shown are ATB based on coolant boiling temperature of 212°F (water at one atmosphere) and 258°F (44 percent ethylene glycol, 15 psi pressure cap).

A rough estimate of the effect of enclosures on cooling system capacity may be obtained by examining the increase of water temperature relative to ambient. The percentage of this increase is given in Table 5 for the three vehicles. Since heat transfer is proportional to temperature difference, this table represents the reduction in cooling capacity of the radiator. Noting that the changes for the Ford at 60 mph and for the

Table 2

Operating Temperatures: Plymouth Horizon

a. Recorded Temperatures, °F

Mode	Configuration	Water	Engine Oil	Trans. Oil	Grill	Behind Engine	Air Flow
60 mph	Stock	175	220	191	84	114	2200 fpm
	Enclosure	190	243	223	85	120	1500 fpm
	Ambient = 82° stock test, 84° enclosure test						
Idle	Stock	161	180	176	88	128	Fan locked on
	Enclosure	186	200	190	92	155	
	Ambient = 88° stock test, 84° enclosure test						
Idle	Stock	196	202	191	92	155	Fan on 50%
	Enclosure	200	210	203	95	156	Fan on 70%
	Ambient = 88° stock test, 84° enclosure test						
Idle	Stock	205	197	191	89	160	Fan Disconnected
	Enclosure Start	185	198	190	90	142	
	Enclosure 5 Min.	235	205	205	135	130	
	Ambient = 88° stock test, 84° enclosure test						

Table 2 (Continued)

b. Calculated Temperatures For 100°F Ambient

Mode	Configuration	Water	Engine Oil	Trans. Oil	Behind Engine	Air-To-Boil	
						Boil = 212°	Boil = 258°
60 mph	Stock	193	238	209	132	119	165
	Enclosure	206	259	239	136	106	152
	Increase	13	21	30	4	-13	-13
Idle D Fan on 100%	Stock	173	192	188	140	139	185
	Enclosure	202	216	206	171	110	156
	Increase	29	24	18	31	-29	-29

Table 3

Operating Temperatures: Ford Pinto

a. Recorded Temperatures, °F

Mode	Configuration	Water	Engine Oil	Trans. Oil	Grill	Behind Engine	Free Stream
60 mph	Stock	195	237	202	88	120	87
	Enclosure	180	228	195	74	110	74
	Ambient = 87° stock test, 74° enclosure test						
Idle	Stock	213	215	208	90	175	95
	Enclosure	221	223	221	79	193	80
	Ambient = 85° stock test, 80° enclosure test						

b. Calculated Temperatures for 100°F Ambient

Mode	Configuration	Water	Engine Oil	Trans. Oil	Behind Engine	Air-To-Boil	
						Boil=212°	Boil=258°
60 mph	Stock	208	250	215	133	104	150
	Enclosure	204	252	219	134	108	154
	Increase	-4	2	4	1	4	4
Idle	Stock	228	230	223	190	84	130
	Enclosure	241	243	241	213	71	117
	Increase	13	13	18	23	-13	-13

Table 4

Operating Temperatures: Chevrolet Van

a. Recorded Temperatures, °F

Mode	Configuration	Water	Engine Oil	Trans. Oil	Grill	Behind Engine	Free Stream	Air Flow
60 mph	Stock	165	215	178	88	122	90	6000 fpm
	Enclosure	158	215	173	75	114	75	6000 fpm
	Ambient = 80° stock test, 75° enclosure test							
Idle	Stock	176	185	178	92	150	92	
	Enclosure	179	185	175	83	151	88	
	Ambient = 80°, both tests							

b. Calculated Temperatures for 100°F Ambient

Mode	Configuration	Water	Engine Oil	Trans. Oil	Behind Engine	Air-To-Boil	
						Boil = 212°	Boil = 258°
60 mph	Stock	185	235	198	142	127	173
	Enclosure	183	240	198	139	129	175
	Increase	-2	5	0	-3	2	2
Idle	Stock	196	205	198	170	116	162
	Enclosure	199	205	195	171	113	159
	Increase	+3	0	-3	+1	-3	-3

Chevrolet are within the estimated experimental error, the effect of the enclosures may be approximately summarized as:

- The Plymouth's cooling system was degraded both at 60 mph and at idle;
- The Ford's cooling system was degraded at idle;
- The Chevrolet was not adversely affected.

Table 5

Reduction of Cooling Capacity of Radiator

	Idle (%)	60 mph (%)
Plymouth	40	14
Ford	10	-4
Chevrolet	3	-2

The change in performance of a cooling system is, of course, more complex than just changes to the water temperature. Oils are cooled both through the water and through the oil pans. The interrelationship between the various fluids is discussed in Section 7, where cooling system design changes are presented.

6.2 Acoustical Performance of Enclosures

Figures 7 through 9 show the measured noise levels at 25 feet for the no-load and full-throttle kickdown tests. Table 6 summarizes the noise reductions achieved by the three enclosures. These values are consistent with those expected.[1]

Table 6

Noise Reduction of Enclosures

Plymouth	3 dB
Ford	4.5 dB
Chevrolet	2.5 dB

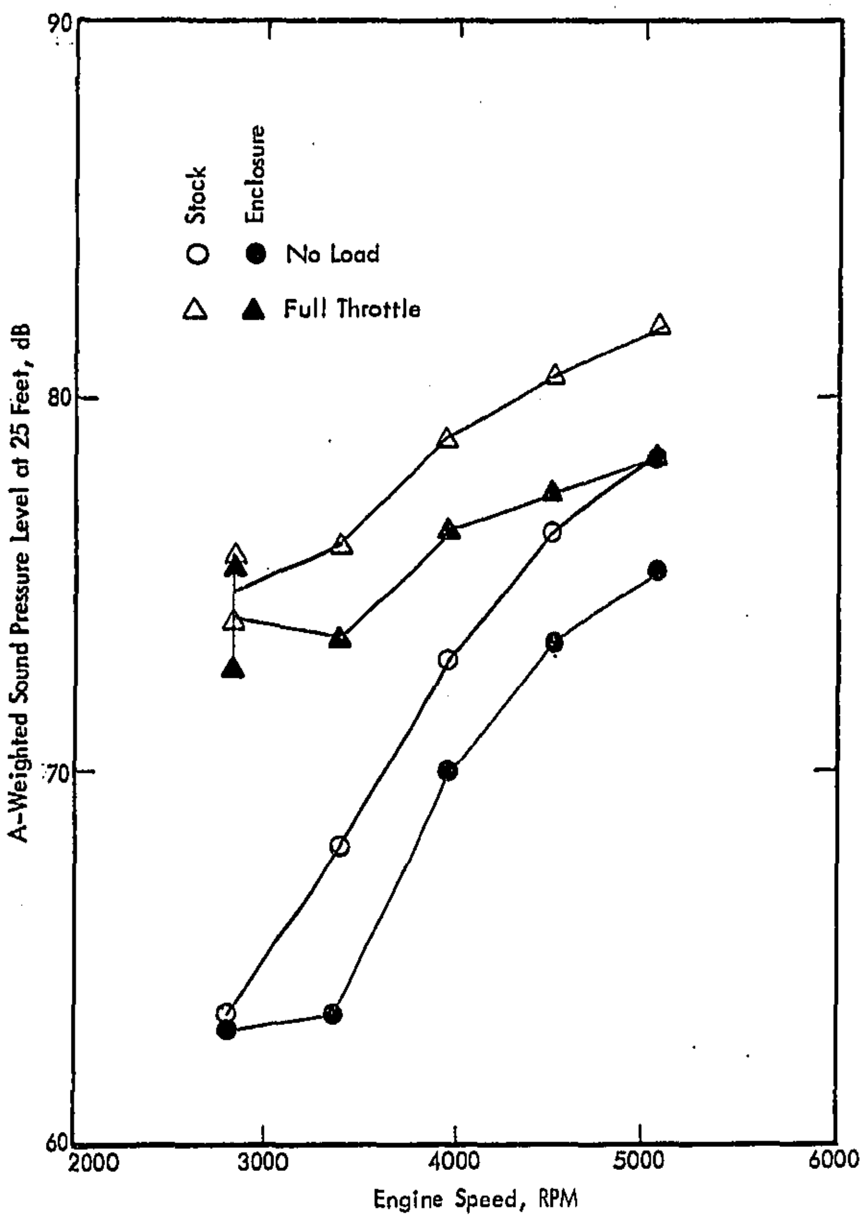


Figure 7. Noise Levels, Plymouth Horizon.

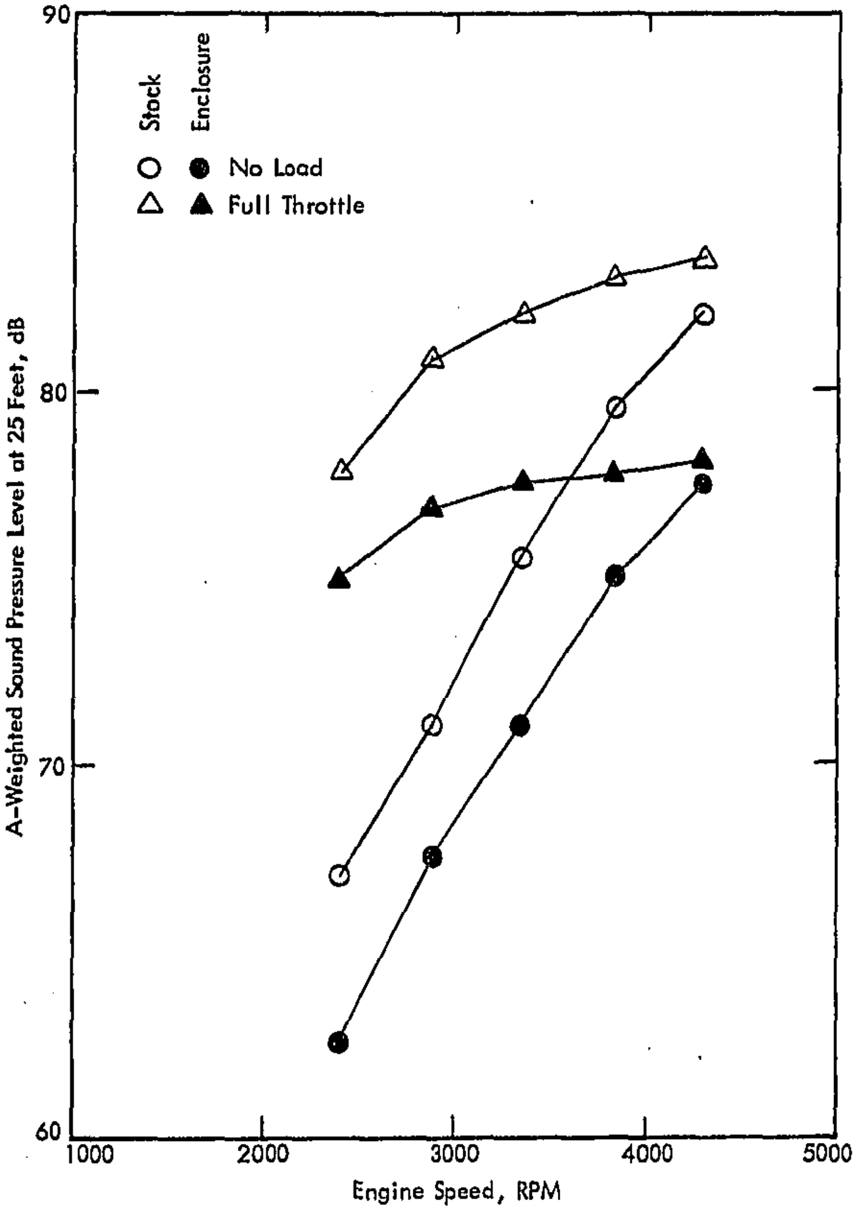


Figure 8. Noise Levels, Ford Pinto.

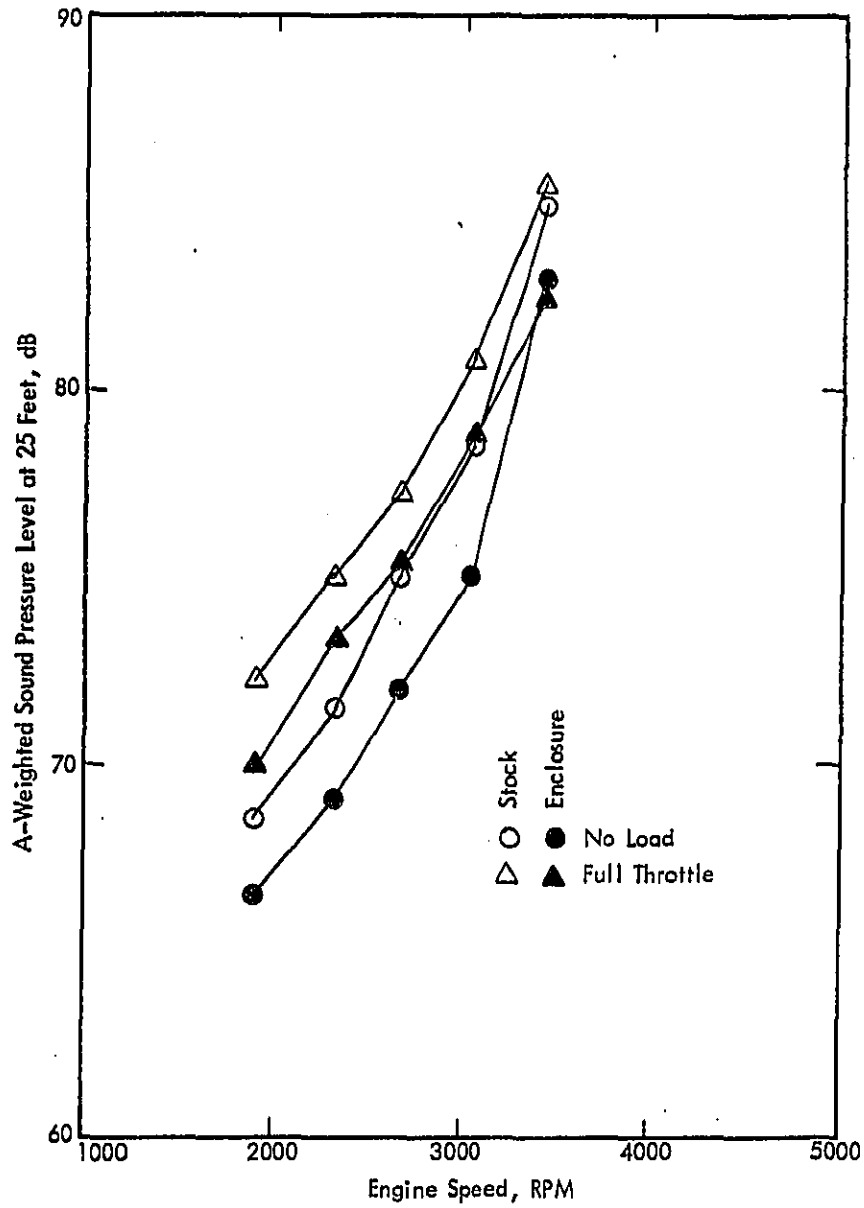


Figure 9. Noise Levels, Chevrolet Van.

7.0 COOLING SYSTEM MODIFICATIONS

7.1 Heat Transfer Components

The three vehicles tested had liquid cooling systems typical of light vehicles. This type of cooling system is a liquid coupled indirect-type heat exchanger. The liquid coolant accepts heat from surfaces within the engine block, and this is rejected to the air through a separate liquid-air heat exchanger. In addition to this basic engine cooling arrangement, the automatic transmission oil is cooled in part through a liquid-liquid heat exchanger in the radiator, and some cooling of engine and transmission oil occurs at their respective oil pans.

The overall heat rejection of the engine/transmission system may be written as:

$$\dot{Q} = H_{rad} (T_w - T_a) + h_p A_{op} (T_{eo} - T_a) + h_p A_{tp} (T_{to} - T_a) \quad (1)$$

where $\dot{Q}$ = total rate of heat rejection.

H_{rad} = heat transfer of radiator, per degree difference between water and air temperature.

h_p = heat transfer coefficient of a flat plate exposed to air flow.

A_{op} = effective surface area of engine oil pan.

A_{tp} = effective surface area of transmission oil pan.

T_w = radiator water temperature.

T_{eo} = engine oil temperature.

T_{to} = transmission oil temperature.

T_a = air temperature.

The overall heat rejection is from two sources, the engine and the transmission:

$$\dot{Q} = \dot{Q}_{eng} + \dot{Q}_{trans} \qquad (2)$$

The transmission heat rejection is through two mechanisms:

$$\dot{Q}_{trans} = H_{tc} \; (T_{wo} - T_{to}) + \dot{Q}_{tp} \qquad (3)$$

where H_{tc} = heat transfer of transmission cooler, per degree difference between oil and water temperature;

T_{wo} = radiator temperature at the transmission oil cooler location;

$\dot{Q}_{tp}$ = heat rejection of transmission pan = $h_p \, A_{tp} \, (T_{to} - T_a)$.

Equations (1) through (3) form a simplified representation of the heat flow. It is assumed that the oil pans may be treated as flat plates in contact with air at ambient temperature. It is also assumed that the heat transfer of each component may be written in terms of a single inlet temperature. Provided that Equation (1) is used only for comparison of similar cases, this is reasonable; the effect of temperature drop may be considered to be grouped with the coefficients H and h. It should be pointed out that the heat transfer coefficients H and h are each complex functions of flow, material properties, and geometry. The functional dependences required for this analysis will be described as needed.

An important feature of Equations (1) through (3) is the interrelationship between transmission and water temperatures. If water temperature rises, transmission temperature will also rise even with no other specific loss to transmission cooling capability. This must be properly treated when analyzing cooling system performance changes.

7.2 Heat Rejection Requirements — Plymouth Horizon

7.2.1 Quantity of Heat Rejected

Consider a vehicle travelling at 60 mph. The power required is mostly that due to aerodynamic drag:

$$P = \tfrac{1}{2}\rho \, V^3 \, C_D \, A \qquad (4)$$

where ρ = density of air.

V = speed.

C_D = drag coefficient.

A = frontal area.

For the Plymouth Horizon tested, $A \approx 25\ ft^2$ and C_D is estimated to be about 0.5. The power delivered to the driving wheels at sea level and $V = 60$ mph is then 18.4 HP. (This calculated power at 60 mph is consistent with the power at 50 mph specified in the EPA air emission test procedure.[3]) Following the general rule that one-third of the power generated in the cylinders of an internal combustion engine is usable power (i.e., that delivered to the driving wheels), one-third is lost through the exhaust, and one-third is rejected through the cooling system, the cooling system must reject about 18.4 HP. Converting to heat transfer units of BTU/minute,

$$\dot{Q} = 780 \text{ BTU/minute} \qquad (5)$$

The additional heat rejected by an automatic transmission is on the order of 5 to 10 percent of this.

7.2.2 Heat Rejection Capacity

Radiator

Consider the Plymouth Horizon in stock condition. The radiator frontal area is about 2 square feet, and air flow at 60 mph is about 2200 feet per minute. The total mass flow available for cooling is:

$$\dot{M} = 337 \text{ lbs/minute} \qquad (6)$$

Using the specific heat of air at constant pressure $Cp = 0.25$ BTU/°F, the heat capacity of this air stream is:

$$\dot{Q} = 84.3 \text{ BTU/}^\circ\text{F} - \text{min.} \qquad (7)$$

Comparing with Equation (5), the air stream through the grill is capable of absorbing the total heat rejection with a temperature increase of 9.3°F. Similar net results apply to the other two vehicles. Since this is small compared to the air-water temperature difference, it follows that at high speed there is a considerable margin in the air cooling available. The limitation, if any, is in providing a radiator which can transfer the heat at an acceptable coolant temperature.

Oil Pans

Consider the oil pan to be a flat plate parallel to flow at the vehicle speed. At 60 mph, the Reynolds number is 5.5×10^5 per foot, so that the flow is turbulent. Using the turbulent boundary layer heat transfer calculation procedure in Reference 4, the heat transfer coefficient h_p is:

$$h_p = 5.9 \times 10^{-6} \frac{R^{.8}}{\ell} \text{ BTU/min-ft-}^\circ\text{F} \tag{8}$$

where R = Reynolds number.
ℓ = length of plate.

For the Plymouth at 60 mph, $\ell = 1/2$ foot and $R = 2.75 \times 10^5$, so that

$$h_p = 0.265 \text{ BTU/minute-ft}^2\text{-}^\circ\text{F}$$

The oil and transmission pan areas are each about one square foot. Using the oil and air temperatures given in Table 2,

$$\begin{aligned} \dot{Q}_{op} &= 36.6 \text{ BTU/min.} \\ \dot{Q}_{tp} &= 28.9 \text{ BTU/min.} \end{aligned} \tag{9}$$

Each of these is less than 5 percent of the total heat rejection, Equation (8).

Transmission Cooler

A direct measurement of the heat transfer is not possible from the measurements made; however, an indirect estimate is possible by comparing the stock and enclosure cases. The enclosure essentially eliminates the oil pan heat transfer calculated above, so that from Equation (3):

$$\dot{Q}_{trans} = H_{tc} (T_{to} - T_{wo}) + \dot{Q}_{tp} = H_{tc} (T^e_{to} - T^e_{wo}) \tag{10}$$

where $(\ )^e$ denotes the temperature with the enclosure. Solving for H_{tc},

$$H_{tc} = \frac{\dot{Q}_{tp}}{T^e_{to} - T_{to} - T^e_{wo} + T_{wo}} \tag{11}$$

Although T^e_{wo} and T_{wo} are not known, the difference is approximately equal to $T^e_w - T_w$. Thus,

$$H_{tc} = 1.7 \text{ BTU/min-}^\circ\text{F} \tag{12}$$

If it is assumed that $T_{wo} = T_w - 10^\circ$ (a typical design difference), then the total transmission heat rejection is

$$\dot{Q}_{trans} = 73.1 \text{ BTU/min} \tag{13}$$

This is about 9 percent of the total estimated heat rejection, and the heat transfer from the pan is about 40 percent of the total transmission heat rejection. All else being equal, the heat transfer lost from the transmission oil pan can be regained either by increasing the effective area of the transmission cooler by about 2/3 or modifying the water cooling system to increase $T_w - T_{wo}$ by about 2/3. Note that if $T_w - T_{wo}$ is initially greater than 10°F, this estimate is conservative.

The need for such a specific modification is discussed in Section 7.3.

7.2.3 Degradation Due to Enclosure

The degradation of the cooling system by installing the enclosure may be summarized:

1. At 60 mph, 65.5 BTU/min ordinarily rejected by the oil pans must be rejected by the radiator. This increases the requirements on the radiator by 8.4 percent.
2. The air flow through the radiator at 60 mph is reduced by about 32 percent. Data in Reference 5 indicates that cooling capacity of finned flat tube radiators as used on cars would be reduced by 0 to 17 percent for this reduction in flow.
3. The water temperature increase shown in Table 2 indicates a net degradation in radiator heat capacity of 13 percent at high speed. This is consistent with 1 and 2 above.
4. At idle, the water temperature above ambient increased by about 40 percent. Oil temperature increases were less than this, indicating that they were following the water and are not critical in themselves. The temperature behind the engine increased comparably to the water temperature.

The means by which the original cooling may be restored are discussed below.

7.2.4 Required Modifications

High Speed

Restoration of the original water temperature, accepting the air flow restriction, would require an increase in radiator area of about 13 percent. If this were accomplished by adding thickness to the existing radiator, somewhat more than 13 percent increase would be needed because the air would be warmed in the front part. However, the increased temperature of the air is only about 15°F for the reduced flow, so that increasing the thickness by about 15 percent would be required.

The transmission cooler would need to be increased in size by about 2/3 from its present dimensions. Depending on space available, a larger bottom tank might be needed. Reduction of bottom tank temperature would not be a feasible approach, as increase of $T_w - T_{wo}$ by 2/3 is equivalent to increasing the total heat transfer capacity by 2/3.

Low Speed

Referring to Table 2b, the temperature behind the engine increased by as much as the water temperature, and is very nearly the same as the water temperature under stock conditions. This indicates that the limiting factor is the restricted air flow; increasing radiator size alone would not restore the cooling capacity. The major problem is that the opening at the rear of the enclosure is limited to an area of about 1 ft^2 between the cross-member and the firewall. This is about half the area of the radiator. There are three alternative solutions to this problem:

- Replace the existing cooling fan with one which has two to three times the flow capacity for the enclosure configuration. A first estimate of fan modification requirements may be made from the fan laws.[6] Assuming geometrically similar fans, doubling the flow requires either twice the fan RPM or a 26 percent increase in diameter. Doubling fan speed would increase fan noise by about 15 dB and increase power required by a factor of 8. Increasing the diameter would increase fan noise by 7 dB and increase power by a factor of 3.2.
- Modify the cross-member or firewall to obtain at least one square foot of additional exit area.

- Noting that with a pressurized cooling system, the air-to-boil temperature is 152°F, so that boiling over is not expected, accept the higher temperatures. The fluid temperatures are about what they would be if the thermostat were functioning; it is only the under-hood temperature which is raised. The elevation above ambient is about 80 percent higher than the stock case.

The actual design solution can be a combination of partial applications of all three alternatives.

7.3 Cooling System Requirements — Ford Pinto

The Ford exhibited increased temperatures with the enclosure only for idle condition. The water temperature difference above ambient increased by about 10 percent; oil temperatures essentially followed the water. Temperature behind the engine rose by about 25 percent. Increasing the air flow by about 25 percent would reduce the under-hood temperature, and is consistent with the flow increase required to provide 10 percent additional radiator cooling.

The vehicle in its present form was equipped with a four-blade direct driven fan, and had no radiator shroud. Experience in the DOT quiet truck program[7] indicated that a properly designed fan shroud can increase flow by 10 percent. Additional flow increase can be achieved by increasing blade area and/or fan speed. Any noise increase associated with this modification can be eliminated by using a clutch fan.

Modifications required for the Ford are then:

- Install a radiator fan shroud.
- Replace the existing fan with a larger or faster one delivering about 15 percent more flow. This would require either a 15 percent speed increase or a 5 percent larger diameter geometrically similar fan.[6] A fan clutch will be needed to avoid noise at driving speeds. Alternatively, an electric demand fan could be used.

7.4 Cooling System Requirements — Chevrolet Van

No modifications are required.

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