75-15 AB

Chrysler Baseline Gas Turbine Vehicle Tests (January 74 - October 74)

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Emission Control Technology Division
Office of Air and Waste Programs
Environmental Protection Agency

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BACKGROUND

The Alternate Automotive Power Systems Division (AAPSD) of the Environmental Protection Agency (EPA) is sponsoring efforts to develop automotive gas turbine engines as alternatives to the spark ignition Otto Cycle engine. The goal is a practical power plant with emission controls and fuel economy superior to the Otto Cycle.

Chrysler Corporation has conducted a Baseline Engine Program under Contract 68-01-0459. Recent component improvements are to be evaluated in this program. The improvements best able to meet program goals will be incorporated in an Upgraded Engine design which will be built and then demonstrated in a vehicle.

The Emission Control Technology Division (ECTD) of the Office of Mobile Source Air Pollution Control was requested by AAPSD to devise a method for measuring gas turbine vehicle exhaust emissions and test the vehicle. The test program was conducted by the Technology Assessment and Evaluation Branch of ECTD.

VEHICLE DESCRIPTION

The vehicles tested were Plymouth Satellites, Cars 667 and 671, equipped with the Chrysler sixth generation gas turbine engine coupled to an automatic transmission. The cars are described in detail in the Vehicle Description Table on the following page. The same burner assembly was used in both cars.

The engine is a low pressure ratio regenerative engine with variable power turbine nozzles. The regenerators are used to improve engine efficiency by extracting waste heat from the turbine exhaust and using it to heat the compressed inlet air. Engine components are driven by the compressor turbine and vehicle accessories are driven by the power turbine (see Figure 1). Neutral was deleted from the transmission to protect the power turbine from overspeed. Auxiliary accessories are provided for power brakes, power steering, air conditioning with reheat capability, and the hot water passenger compartment heating system.

The body and chassis were modified to accept the gas turbine engine. This required new front suspension crossmembers, a modified front end body structure, relocation of the torsion bar suspension, and an additional flexible joint in the relocated steering gear. The engine air inlets are located on the sides of the front fenders immediately ahead of the wheels. Engine exhaust is through two large ducts terminating ahead of the rear axle (see Figure 2).

To the vehicle operator, the car is the same as the standard Plymouth Satellite. Externally the only difference is the engine air inlets. On the instrument panel, a gauge was added to indicate

Test Vehicle Description
Chassis Model Year/Make - 1973 Plymouth Satellite 4 Dr. Sedan

Engine (Design Specifications)

Type	Brayton cycle, sixth generation (A-128-1) Chrysler gas turbine.
Maximum power @ rpm	150 hp @ 3500 rpm (reduction gear output rpm)
Compressor - single stage	
inlet temperature	85°F
inlet pressure	29.92 in. hg
pressure ratio maximum	4.1 to 1 (compressor outlet pressure ÷ compressor inlet pressure)
maximum fuel consumption	81.5 lbs./hr.
maximum airflow	2.29 lbs./sec.
Power Turbine	
maximum speed	45,500 rpm
reduction gear ratio	9.6875 to 1
variable power turbine inlet nozzles	
Regenerator	
type	Metallic
inlet temperature (max conditions)	1350°F
outlet temperature (max conditions)	595°F
Fuel injection	Air atomizing nozzle
Fuel requirement	Diesel no. 1, Diesel no. 2, gasoline (Table 1)

Drive Train

Transmission type	Standard Chrysler 3-speed automatic (no neutral) with torque converter

Chassis

Type	Unitized with isolated front suspensions
Tire size	G 78 x 14
Curb weight	4350 lbs./1973 kg
Inertia weight	4500 lbs./2041 kg
Passenger capacity	6

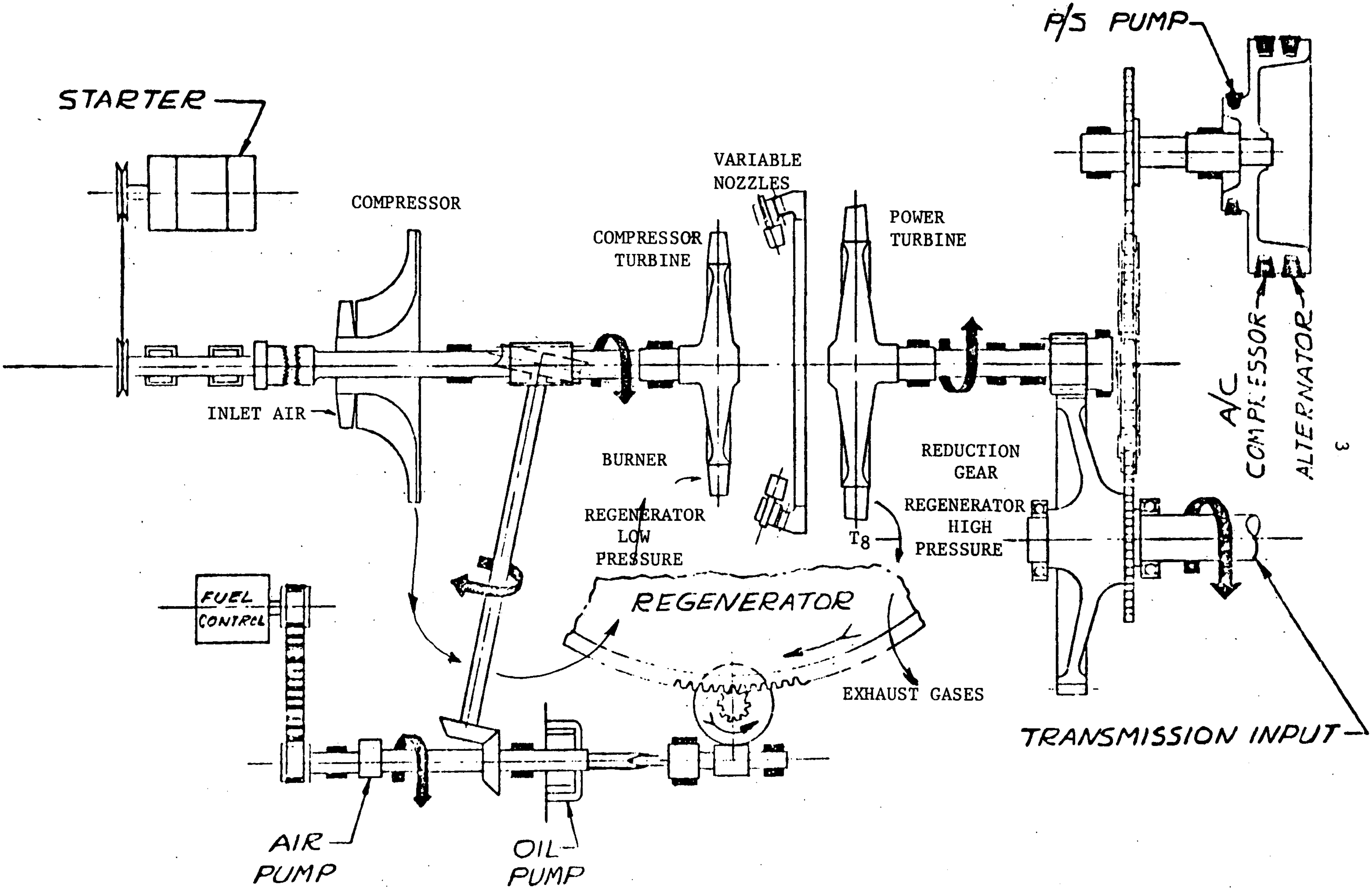

Figure 1 - Sixth Generation Chrysler Gas Turbine

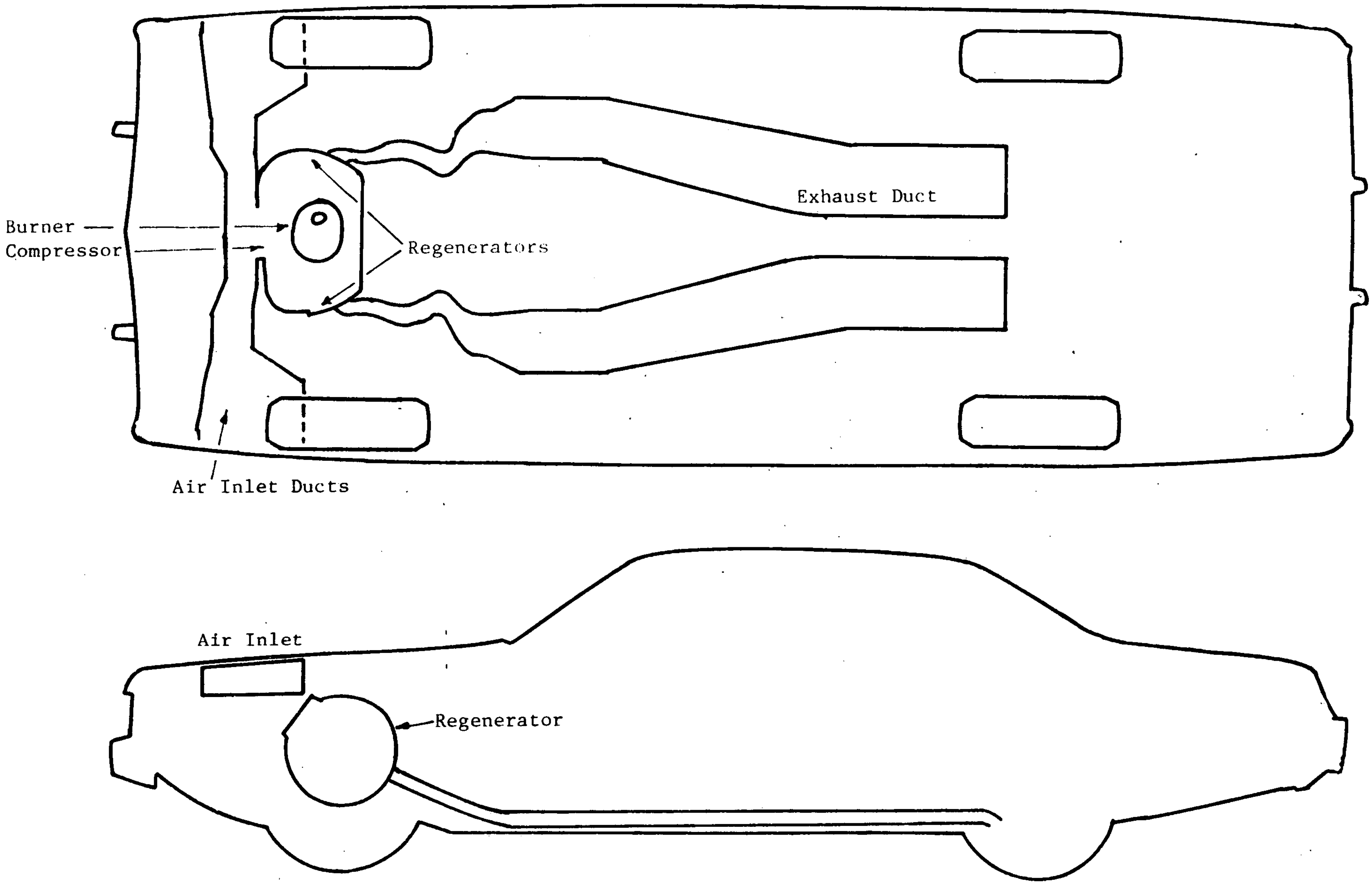

Figure 2 - Baseline Turbine Powered Vehicle

exit gas temperature (T8) at the regenerator inlet. The automatic engine start sequence is initiated by momentarily moving the key to start with the transmission in park. The car was ready to be driven as soon as the oil pressure light went out, usually 5 to 10 seconds after initiating the start sequence. Use of different fuels requires no vehicle adjustment.

Emission control is incorporated into the design of the engine combustion chamber. This requires a complete burning of the fuel to maintain low levels of Hydrocarbons (HC) and Carbon Monoxide (CO) and simultaneously avoiding the high temperatures which cause the formation of Nitrogen Oxides (NOx).

TEST PROCEDURES

Tests were conducted for gaseous exhaust emissions, fuel economy, sulfate emissions, particulate emissions, ambient temperature effects, ambient background pollutant effects, odor, noise, gradeability, and driveability. Two similar vehicles were used during this series of tests, but the same burner assembly was retained. The engines required some service and adjustment.

Emission Procedure

Since the vehicle exhaust flow rate exceeds the capacity of present EPA test equipment, a new procedure was developed to permit evaluation of the Baseline Engine. This procedure uses the dynamometer test room as a constant volume sampler (CVS) and is analogous to the Federal Test Procedure (FTP). This method is an extension of EPA efforts to improve the method for measuring vehicle evaporative running losses.

To use the room as a CVS, continuous samples are taken of the ambient air flowing into and out of the room (see Figure 3). The emissions are equal to the product of room airflow rate (Q), time (t), net pollutant concentration (C), and a pollutant constant (K).

Mass of Pollutant $M = QCtK$

K = 16.33 gm/cu. ft. for HC
K = 32.97 gm/cu. ft. for CO
K = 51.81 gm/cu. ft. for CO_2

K = 54.16 gm/cu. ft. for NOx
C = C (sample) - C (background)

The room flow rate is calculated either by using a propane bomb to inject a known mass of propane into the room or by using a critical flow orifice (CFO) to inject either propane or carbon dioxide at a known rate:

$Q = \frac{m}{Ctk}$ for bomb or $Q = \frac{m}{Ck}$ for CFO

K = 51.9 gm/cu. ft. for propane.

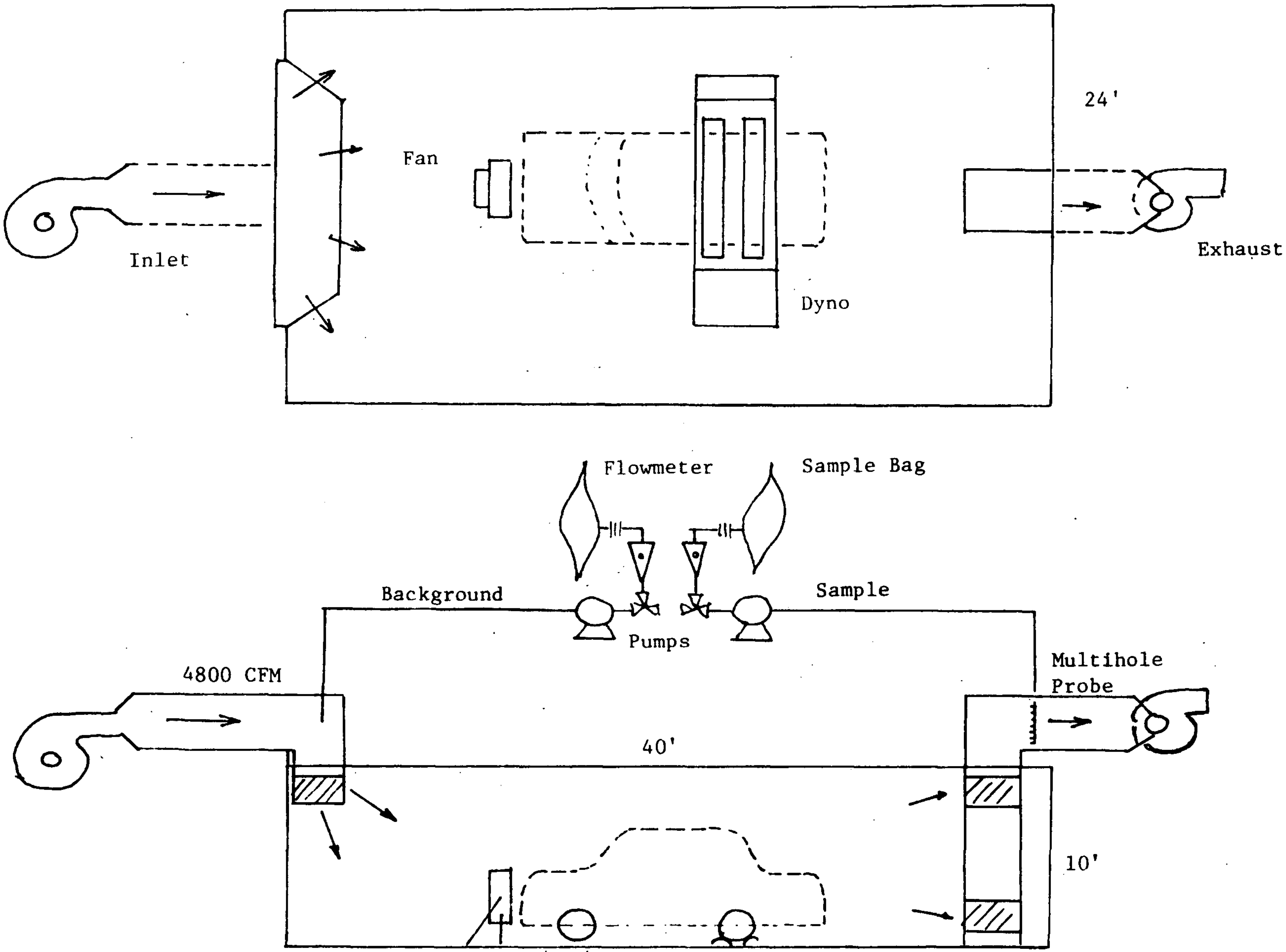

Figure 3 - Room CVS Sampling System

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To test a vehicle the dynamometer room air flow rate is first calculated with no vehicle in the room. Then the test vehicle is placed in the room and emissions are measured using a technique similar to the standard Federal Test Procedure. For transient test cycles, sampling is continued 5 minutes after vehicle shutdown to ensure collection of all pollutants from the room air. Room conditions are continuously monitored during testing and the room flow rate is rechecked after the vehicle leaves the room.

The turbine engine raw exhaust is considerably diluted by the excess (secondary) air the turbine engine uses. The exhaust is further diluted by the room air handling system. Thus for a clean engine pollutant concentrations are very low when this procedure is used and the samples must be analyzed using instruments capable of accurately measuring at these very low levels (HC < 10 ppm propane, CO < 50 ppm, CO_2 < 1%, NOx < 25 ppm).

The validity of the procedure depends upon constant room air flow and proper sampling. The earlier work to determine vehicle running losses had shown the air flow usually to be 8000 standard cubic feet per minute (scfm). This procedure was then tried for measuring steady state vehicle emissions and crosschecked using a standard CVS system. The standard CVS was exhausted into the room and thus sampled by the room CVS system. By careful attention to test parameters, results could be agreeable within 10 percent.

Due to the considerable exhaust dilution, the background bag pollutant levels were a significant fraction of the sample bag pollutant level. Therefore the room air handling was restricted to its minimum flow rate, about 4800 scfm. This raised the sample bag concentration levels and made room airflow check and emissions results more consistent.

Evaporative emissions tests were not performed when the vehicle was tested with gasoline, and evaporative emissions tests are not required for diesel-fueled vehicles.

Except as modified above, exhaust emissions tests were conducted according to the 1975 FTP (75 FTP) described in the Federal Register of November 15, 1972. Additional tests included the EPA Highway Cycle and steady state tests. All tests were conducted using an inertia weight of 4500 pounds (2041 kg) with a road load setting of 13.9 horsepower (10.37 kW) at 50 miles per hour (80.5 km/hr). These tests were done using all three vehicle fuels.

Humidity and Temperature Procedure

The effects of humidity and ambient temperature on vehicle emissions were measured with a series of steady state tests. The test procedure was similar to the emissions procedure. The vehicle was operated at a constant speed, the test room conditions were allowed to stabilize, and emissions were then sampled for 5 minutes at each test condition. Mass Emissions were calculated as before. For these tests humidity was varied between 50 and 90 percent, temperature was varied between 50°F and 110°F, and vehicle speeds were varied between 15 and 60 mph (24.1 and 96.6 km/hr).

Fuel Economy Test Procedures

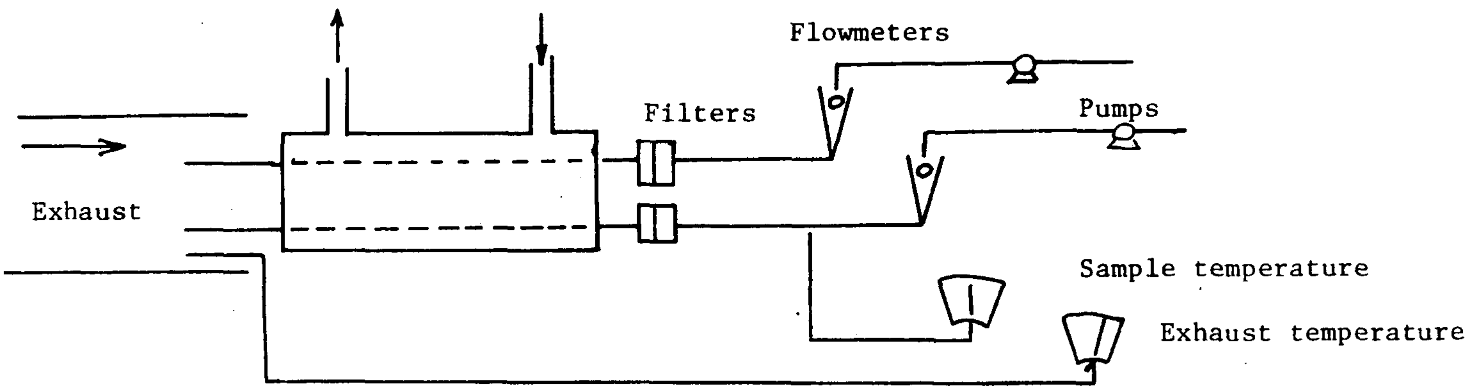
Vehicle fuel economy was tested by two different methods. Fuel economy results were calculated from the emissions test performed using the CVS procedure while an inline fuel meter was used to measure fuel consumption for all non-CVS tests.

The CVS tests included the most parameters. The car was tested both at constant speeds and in transient driving cycles using three fuels and at several temperature and humidity conditions.

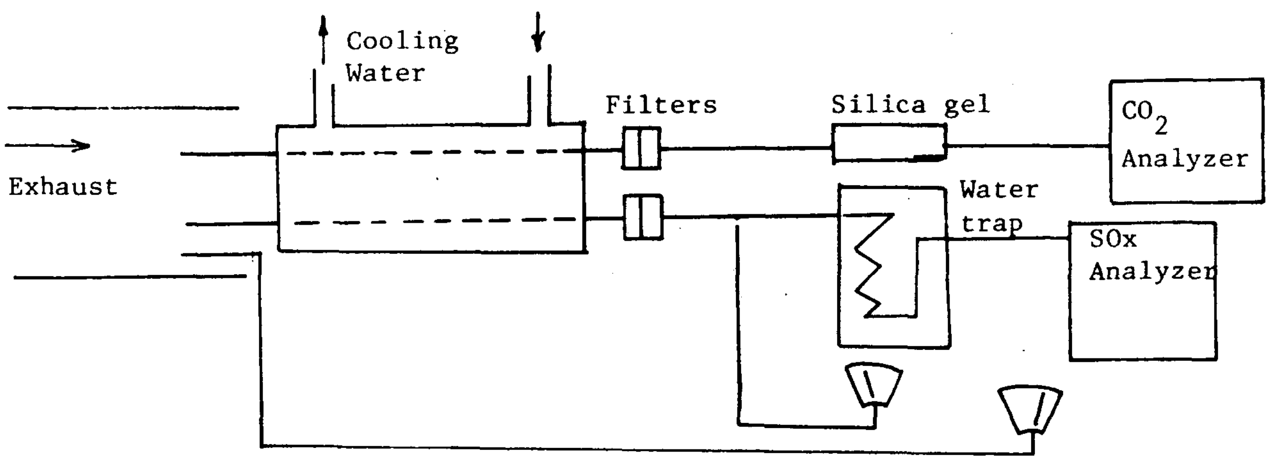
The vehicle fuel system was modified to eliminate the fuel bypass for all tests using the inline fuel meter. This was done to make fuel flow measurements easier. Tests using this inline fuel meter were conducted on a large roll electric dynamometer.

Sulfate and Particulate Test Procedures

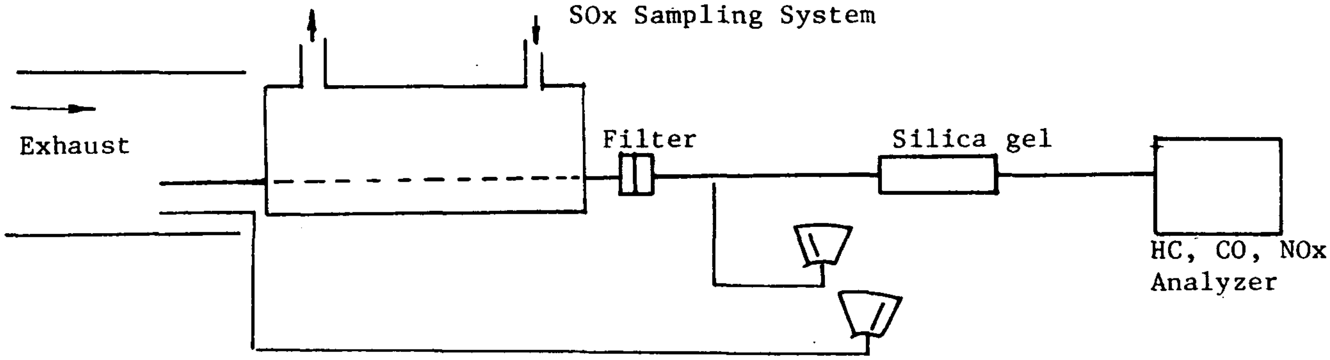
Sulfates and particulates testing were conducted using an electric dynamometer with samples collected from inside the vehicle exhaust duct using a sampling system parallel to the flow. A thermocouple was installed at the sample inlet to monitor the exhaust gas temperature. Samples were collected using a dual parallel system consisting of two straight lengths of stainless steel tubing, each with a water jacket to cool the flow to 100°F. Filters were placed at the ends of each to trap the samples, and thermocouples were used to monitor temperature at each filter. Flow rate through the filters was measured by flowmeters upstream of sample pumps and controlled with metering valves. The leading edges of the sample probes were ground to knife edges to facilitate isokinetic sampling of particulates. A glass fiber filter was used to trap particulates and a polytetrafluoroethylene (1.0 um) filter was used to trap sulfates. (See Figure 4).



Sulfate and Particulate Sampling System



SOx Sampling System



Ambient Sampling System

Figure 4 - Exhaust Sampling Systems

All testing was done at steady state conditions with sample flow rates adjusted so that the vehicle exhaust gas velocity at the sampling position equalled the sample velocity. The necessary adjustments were determined from the fuel flow rate, exhaust duct area, sample probe area, sample temperature, and carbon dioxide concentrations. (See Appendix). Samples were taken at 60 mph for one to three hours.

Additional steady state tests were made for emissions of sulfur products using a TECO Model 40 SO_2 (sulfur dioxide) analyzer, a device which uses the principle of pulsed ultraviolet fluorescence to detect SO_2. The sampling system consisted of water cooled stainless steel tubing, a filter, a cooled water trap, and the analyzer. Samples were taken in the vehicle exhaust duct. (See Figure 4).

Ambient HC, CO, and NOx Effects Procedures

The effects of ambient HC, CO, and NOx levels on vehicle emissions was investigated using procedures and equipment similar to those used for sulfates and sulfur dioxide. The sampling system consisted of the water cooled tubing, inlet and outlet sample temperature thermocouples, a filter, silica gel for water removal, and an analyzer for HC, CO, and NOx. (See Figure 4).

Ambient levels were simulated by flowing gases of known concentrations of HC, CO, or NOx into the vehicle air inlet through an accurate flow measuring device. From this the inlet HC, CO, or NOx mass flow rate was determined. Exhaust mass air flow rate was determined from the fuel flow rate and carbon dioxide concentration.

Since the volume flow rate in moles equals the mass flow rate of the flowing gas divided by the molecular weight of the flowing gas, the additional emission concentration is expressed thus:

$$\text{Concentration, ppm} = 10^6 \times \frac{m_i}{M_i} \div \frac{f \div (\%\ CO_2)}{M_f}$$

where m_i = mass flow rate of flowing gas
M_i = molecular weight of flowing gas
f = fuel flow rate
M_f = molecular weight of fuel

HC, CO, and NOx gas flow rates and gas concentrations were chosen to give inlet air emission levels that would span the ranges seen under the most severe background levels. Tests were conducted at steady state conditions using vehicle road load (Table IX).

Odor Measurement Procedures

At the conclusion of tests at the EPA laboratory the vehicle was shipped to Southwest Research Institute (SwRI) for odor tests. SWRI has done extensive research and development work in odor testing and has recently tested diesel vehicles in a research study for EPA. Highly trained panelists were used to rate the odor in terms of a reference standard.

No standard procedure currently exists for automotive odor evaluation. However, the procedure used by SwRI for the turbine vehicle is one that has been used for 8 years in the evaluation of odor control techniques for diesel powered vehicles. The odor reference was the EPA Diesel Odor Quality - Intensity Rating System kit. The kit consists of squeeze bottles each partially filled with chemical mixes yielding a different intensity or odor. The kit includes an overall "D" diesel odor in twelve steps of increasing concentration. Each concentration is double the preceeding in order to parallel the non-linear human response to odor. The "D" odor is made up of four sub-odors or qualities. These comprise burnt smoke "B", oily "O", aromatic "A", and pungent "P" qualities each in an intensity of 1 through 4, with 4 being the strongest.

The vehicle exhaust was diluted 100:1 and the diluted sample was then immediately piped to the odor panel for evaluation.

The vehicle was operated using Diesel No. 1 fuel and 75^{o}F inlet air. An inertia weight of 4000 pounds was used for transient tests and variable loading was used in the steady state tests. Simultaneous exhaust emission measurements were made by sampling the undiluted exhaust during the periods when odor ratings were made. Each panelist rated the odor for D, B, O, A, and P levels and the average was then taken.

Noise Test Procedure

The vehicle was tested for noise using SAE procedure J986a. This test requires sound level measurements from the side of the vehicle while the vehicle is accelerated from 30 mph (48.3 km/hr) at wide open throttle. Testing was done on a straight section of test track.

Gradeability Procedure

The gradeability of the vehicle was tested by determining the excess horsepower available at the rear wheels. A large (4 ft. diameter) roll electric chassis dynamometer was used for this testing. The road load horsepower requirement versus speed was determined from the vehicle manufacturer's data. Estimated rear wheel and drive train losses were subtracted to give a net chassis dynamometer horsepower. These values, Table IX, are close to a typical dynamometer road load curve. From these and the measured values the gradeability of the vehicle was calculated

$$HP = HP_{\text{Road Load}} + \frac{\text{Weight x .01 Percent x Speed}}{3000}$$

$$\text{Percent Grade} = \frac{(HP - HP_{RL}) \times 375}{45 \times \text{Speed}}$$

Testing was done at an inertia weight of 4500 pounds.

Driveability

The vehicle was test driven for driveability ratings by trained technicians on local roads and highways. Evaluation was based in the driveability definitions found in the Appendix.

TEST RESULTS

Emission Results

Exhaust emissions data are listed in Table II (75 FTP) and Table III (Steady State). Results are summarized below for the three fuels.

'75 FTP Composite Mass Emissions
grams per mile
(grams per kilometre)

	HC	CO	NOx	Fuel Economy (Fuel Consumption)
Diesel No. 1 - avg. of 3 tests	.68 (.42)	3.51 (2.18)	2.72 (1.69)	6.5 miles/gal (36.0 litres/100 Km)
Diesel No. 2 - avg. of 2 tests	.68 (.42)	3.77 (2.34)	2.86 (1.77)	7.2 miles/gal (32.0 litres/100 Km)
Gasoline - avg of 2 tests*	2.84 (1.77)	2.28 (1.43)	3.14 (1.95)	6.2 miles/gal (38.0 litres/100 Km)

* The fuel tank evaporative emissions are vented to the atmosphere on this vehicle and are thus collected with the exhaust sample when the room CVS procedure is used. This gave an unknown hydrocarbon contribution to the exhaust sample.

For the EPA Highway Cycle the results were:

EPA Highway Cycle Mass Emissions
grams per mile
(grams per kilometre)

	HC	CO	NOx	Fuel Economy (Fuel Consumption)
Diesel No. 1 - avg. of 3 tests	.23 (.15)	.87 (.54)	1.34 (.82)	12.9 miles/gal (18.3 litres/100 Km)
Diesel No. 2 - avg. of 2 tests	.23 (.15)	.74 (.46)	1.69 (1.05)	12.3 miles/gal (19.1 litres/100 Km)
Gasoline - avg. of 2 tests*	1.77 (1.10)	.83 (.51)	1.55 (.96)	12.7 (18.6 litres/100 Km)

Humidity and Temperature Results

Humidity and temperature were varied during steady state emissions tests to determine their effect on emissions. However, the tests in which these conditions were varied the most (tests 4617 through 4629) experienced a room CVS calibration problem. The room flow check at the end of tests 4625 and 4629 showed a marked rise in flow. A correction factor was developed for those tests to compensate for the flow increase.

Analysis of the data yielded no readily discernible trend in emission rates. Further work is needed.

Fuel Economy Results

Data from the fuel economy tests are listed in Tables III and IV. For the room CVS method the results are summarized below:

	(24.1 Km/hr) 15 mph	(48.3 Km/hr) 30 mph	(72.4 Km/hr) 45 mph	(96.5 Km/hr) 60 mph
Diesel No. 1	8.3 (28.3)	12.6 (18.7)	14.4 (16.3)	15.3 miles/gal (15.4) (litres/ 100 Km)
Diesel No. 2		12.3 (19.1)		14.2 miles/gal (16.6) (litres/ 100 Km)
Gasoline		12.8 (18.4)		15.9 miles/gal (14.8) (litres/ 100 Km)

* See note on page 12

These results show a slight increase in economy from Diesel No. 2 to Diesel No. 1 to gasoline. This is the opposite expected since the fuel energy available per gallon should be decreasing.

For the inline fuel sampling system the averages from Table IV are:

mph (Km/hr)	Fuel Economy miles per gal.	(Fuel Consumption) litres/100 Km
15 (24.1)	10.4	(22.6)
30 (48.3)	15.5	(15.2)
45 (72.4)	15.1	(15.6)
60 (96.5)	13.6	(17.3)
75 (120.7)	12.0	(19.6)

These data are for Diesel No. 1 fuel and the results are close to the expected values. Also the fuel economy is constant over a wide range, with a maximum between 30 and 45 mph which agrees well with manufacturer's test data.

Sulfate and Particulate Results

The results of the sulfate and particulate tests were inconclusive due to sampling problems. Minute pieces of the glass filter were found to adhere to the filter holder and even when these were scraped off and added to the filter, net results sometimes showed a negative weight change. Thus no conclusion can be based on the observed tests.

Sulfate samples showed a net gain of a few ten thousandths of a gram. However, there was considerable variation in the results, with identical tests showing as much as a three-to-one variation in net weight. For these tests sulfates were 24% of the total particulate sample and the sulfates varied between .0015 and .0002 grams per mile. This level is as low as is measured on conventional 1975 prototype vehicles (some with catalysts) tested with low sulfur content (0.03 wt. percent sulfur) when operated on transient cycles.

Due to the considerable variations in results and the low levels observed, additional tests were made for sulfur products in the vehicle exhaust. The data, listed in Table V, show that most of the sulfur is exhausted as sulfur dioxide. The calculated SO_2 concentration at the test conditions is 10.4 ppm. The average for the seven samples is 9.91 ppm, or 95% of the fuel sulfur. Using the accuracy limits of the fuel sulfur content, sulfur dioxide accounts for 90 to 100% of the fuel sulfur.

Since SO_2 accounts for most of the sulfur, and since small amounts of sulfate were measured, the turbine car does not appear to have a sulfate problem. The measured sulfate levels on the turbine car using Diesel No. 1 fuel with 0.2 percent sulfur were no higher than those measured on conventional 1975 model year certification vehicles (some with catalysts) tested with Indolene gasoline with 0.03 percent sulfur. These results are not conclusive, however, since due to the large exhaust flow rates, the turbine car was not tested for sulates under transient conditions as the conventional cars have been. Further testing in this area is needed.

Ambient HC, CO and NOx Results

Although the vehicle conditions were constant at each speed, there was considerable variation in the emission levels observed. Therefore the results are presented in the sequence observed for each pollutant. The data (Table VI) show that higher concentrations of pollutants in engine inlet air generally cause higher concentrations of pollutants in vehicle exhaust. In two tests a negative increase was measure and in three tests there was no change. The increases in exhaust concentrations generally ranged from about 10% to about 80% of the increase in the inlet air concentration (and about 5% to 20% of the exhaust concentration), although in two cases the exhaust pollutant concentration increase was greater than the increase in inlet air pollutant concentration. The effects of the ambient HC and CO levels normally encountered in a laboratory are expected to be minimal.

Odor Results

The test conditions and results are given in Table VII. The overall Diesel rating ranged from .8 to 1.5 except for the cold start which was 3.7. The B, O, A and P ratings ranged from 0 to .7 except for the cold start which was 1.1. The quality summation (B + O + A + P) was about 10 percent higher than the corresponding Diesel "D" rating. For piston engine cars the quality summation usually is about 20 percent higher than the Diesel rating.

SwRI emissions data (Table VII) were in close agreement with Chrysler test data for this engine. Thus the results can be taken as representative of the engine's performance.

Overall, the turbine car when diluted 100:1 had very good ratings and low odor numbers compared to both Diesel and gasoline vehicles previously evaluated at the same condition. Only the cold start odor had any significance.

Noise Results

Discrete frequencies were taken and the required A-weighting applied to arrive at the results in Table VIIIa. Thus the noise level for the car is 73 decibels, the highest average value recorded.

The data in Table VIIIb were taken to obtain additional information on the vehicle. Turbine whine was noticeable but not objectionable inside the car between 35 and 55 mph (56.3 and 88.5 km/hr).

Gradeability

The results are given in Table IX. The vehicle would have been capable of better performance but at the time of the test, the manufacturer did not wish to exceed 90 percent of rated power (90 percent of 44,600 rpm adjusted for 85°F standard day). At zero mph the dynamometer was unable to keep the vehicle stopped when the gas turbine reached 32,000 RPM. At this point the vehicle generated 2700 ft. lbs. of torque at the rear wheels. The vehicle easily met the gradeability goals of the Baseline Engine contract.

Driveability

The vehicle behaved well with no problems other than trace-to-moderate hesitation associated with a lag in turbine response. A driver can partially compensate for this lag by rapidly depressing the accelerator pedal to speed up the turbine and then releasing the pedal slightly to maintain the desired acceleration rate.

CONCLUSIONS

The procedure developed for emission testing the Chrysler Baseline Gas Turbine vehicle, that is using the test cell as a constant volume sampler, appears to be a workable approach. Room air flow calibrations were easily determined and remained relatively stable. During the one hour period required for conducting the '75 FTP and other tests, room air flow remained within ± 10% of the initial value if room temperature variation was less than 20°F and barometric pressure remained constant. These conditions were met except during the high temperature steady state tests.

The effects of the hot exhaust products in the test room being recirculated by the engine was minimal. The test cell airflow was from the front to rear of the vehicle. Air entering the engine inlets was no more than 5 to 10°F warmer than the air entering the room. This temperature rise is typical of standard tests and is most likely due to the room and engine heating the air entering the engine compartment.

The gas analyzers in use at the Ann Arbor Laboratory were found to be capable of accurate determination of gaseous pollutant concentrations at the low levels encountered in turbine vehicles. The major improvement will be the use of a recently-acquired critical flow venturi CVS system having a flow rate of 3000 scfm.

APPENDIX

Tables, Flow Calculations, and Driveability Definitions

TABLE II
MASS EMISSIONS
GRAMS PER MILE

TEST NO.	TYPE	HC	CO	CO_2	NOx	FUEL ECONOMY MPG	FUEL TYPE	CAR INLET	GRAINS H_2O/LB. AIR	AIRFLOW OF ROOM CFM
15-4581	Bag 1 75 FTP	.45	2.99	1336	3.16	7.2	DF 1	67°F	64	4976
	Bag 2	.71	3.97	1670	2.59	5.8	DF 1	63°F	58	4852*
	Bag 3	.43	2.36	1084	2.04	8.9	DF 1	65°F	62	4728*
	Weighted	.58	3.33	1441	2.56	6.7	DF 1			
	HWY	.22	.73	699	1.25	13.8	DF 1	68°F	64	4604
4603	Bag 1 75 FTP	.51	3.02	1307	3.20	7.4	DF 1	67°F	62	4131*
	Bag 2	.76	4.31	1662	2.78	5.8	DF 1	66°F	62	4173*
	Bag 3	.51	2.95	1393	2.50	6.9	DF 1	69°F	59	4215
	Weighted	.64	3.67	1515	2.79	6.4	DF 1			
	HWY	.17	.84	752	1.40	12.9	DF 1	71°F	61	4258
4650	Bag 1 75 FTP	.52	2.48	1233	3.41	7.8	DF 1	82°F	80	4448
	Bag 2	.96	4.07	1673	2.75	5.8	DF 1	70°F	66	4565*
	Bag 3	.78	3.27	1325	2.52	7.3	DF 1	67°F	66	4863*
	Weighted	.82	3.52	1488	2.82	6.5	DF 1			
	HWY	.31	1.04	813	1.37	11.9	DF 1	69°F	64	4800
4698	Bag 1 75 FTP	.74	2.88	1173	3.13	8.6	DF 2	69°F	72	4304
	Bag 2	.87	4.37	1529	2.66	6.6	DF 2	68°F	67.5	4435*
	Bag 3	.60	2.78	1337	2.75	7.6	DF 2	71°F	66	4566
	Weighted	.77	3.63	1403	2.78	7.3	DF 2			
	HWY	.29	.70	784	1.53	13.0	DF 2	72°F	69	4504

Table I
Gasoline Specifications

Item	ASTM Designation	Indolene Specifications	Alternative Power Plant Specifications
Distillation range	D86		
IBT, °F		75-95	100-115
10 percent point, °F		120-135	140-150
50 percent point, °F		200-230	240-250
90 percent point, °F		300-325	330-340
EP, °F (max)		415	425
Sulfur wt. percent max	D1266	.10	.10
Phosphorous, theory		0.0	0.0
RVP, lb.	D323	8.7-9.2(1)	5.5-7.5
Hydrocarbon composition	D1319		
Olefins, percent max		10	30
Aromatics, percent max		35	40
Saturates, percent max		remainder	remainder
Octane, research, min	D2699	as specified by manufacturer	91-93
Pb (organic), gm/U.S. gal.	D526		<.02
Washed gum (max) mgm/gal	D381		4.0
Corrosion (not lower than)	D130		1B
Oxidation stability (not less than)	D525		240+
Nitrogen, wt. percent max (chemically bound & additive introduced	Kjeldahl method		.005

(1) For testing which is unrelated to fuel evaporative emission control, the specified range is 8.0-9.2.

TABLE II - Continued

TEST NO.	TYPE	HC	CO	CO_2	NOx	FUEL ECONOMY MPG	FUEL TYPE	CAR INLET	GRAINS H_2O/LB. AIR	AIRFLOW OF ROOM CFM
4724	Bag 1	.48	3.12	1262	3.10	8.0	DF 2	68°F	67.5	4610
	Bag 2	.71	4.55	1611	3.06	6.3	DF 2	68°F	64	4760*
	Bag 3	.41	3.28	1279	2.56	7.9	DF 2	68°F	64	4910*
	Weighted	.58	3.91	1449	2.93	7.0	DF 2			
	HWY	.18	.78	878	1.85	11.6	DF 2	70°F	66	5060*
4772**	Bag 1	.89	1.67	1230	3.82	7.2	Gasoline	80°F	91	4313
	Bag 2	4.10	2.24	1735	3.66	5.1	Gasoline	79°F	84	4464*
	Bag 3	2.88	1.09	1307	2.78	6.7	Gasoline	76°F	87.5	4615*
	Weighted	3.10	1.80	1512	3.45	5.9	Gasoline			
	HWY	2.08	.93	757	1.37	11.6	Gasoline	73°F	74	4766
4834**	Bag 1	.77	1.78	1206	2.97	7.3	Gasoline	70°F	74	4187
	Bag 2	3.62	3.55	1513	3.04	5.8	Gasoline	79°F	73	4143*
	Bag 3	1.97	1.94	1140	2.29	7.7	Gasoline	70°F	74	4099*
	Weighted	2.58	2.75	1348	2.82	6.5	Gasoline			
	HWY	1.45	.72	641	1.73	13.7	Gasoline	74°F	76	4055*

* Estimated Air Flow

** The fuel tank evaporative emissions are vented to the atmosphere on this vehicle and are thus collected with the exhaust sample when the room CVS procedure is used. This gave an unknown contribution to the exhaust sample.

TABLE III

MASS EMISSIONS
GRAMS PER MILE

TEST NO.	TYPE	HC	CO	CO_2	NOx	FUEL ECONOMY MPG	FUEL	CORRECTION FACTOR	CAR INLET	GRAINS H_2O/#AIR	AIRFLOW ROOM CFM
4617	15 mph	.23	3.12	1151	1.16	8.4	DF 1		58°F	52	4870
4618	30 mph	.09	1.96	954	1.01	10.1	DF 1	1.06	64°F	55	5163*
4619	45 mph	.12	1.09	828	1.08	11.7	DF 1	1.12	68.5°F	60	5456*
4620	60 mph	.10	.58	775	1.39	12.5	DF 1	1.18	74°F	69	5749*
4622	15 mph	.16	4.35	980	.79	9.8	DF 1	1.24	59°F	56.5	6042*
4623	30 mph	.10	1.70	954	.97	10.1	DF 1	1.30	65°F	61.5	6335*
4624	45 mph	.15	1.00	808	1.07	12.0	DF 1	1.36	71°F	66	6628*
4625	60 mph	.13	.50	763	1.38	12.1	DF 1	1.42	79°F	78.5	6922*
4626	15 mph	.46	1.27	1508	2.16	6.4	DF 1		107°F	113	4155
4627	30 mph	.28	.71	808	1.31	10.9	DF 1	1.23	111°F	118	5106*
4628	45 mph	.30	.51	735	1.43	13.2	DF 1	1.46	114°F	129	6056*
4629	60 mph	.31	.44	661	1.71	14.6	DF 1	1.69	118°F	129.5	7008
4663	15 mph	.44	2.88	1139	1.25	8.5	DF 1		85°F	82	4395
4664	30 mph	.13	.87	759	.85	12.8	DF 1		82.5°F	81.5	4413*
4665	45 mph	.21	.55	670	.98	14.4	DF 1		85°F	79.5	4430*
4666	60 mph	.22	.36	641	1.23	15.1	DF 1		85°F	84	4448
4667	15 mph	.25	2.22	1194	1.17	8.1	DF 1		66°F	57	5142
4668	30 mph	.10	1.08	784	.78	12.3	DF 1		67°F	66	5011*
4669	45 mph	.12	.63	668	.81	14.5	DF 1		69°F	68	4880*
4670	60 mph	.14	.34	627	1.09	15.4	DF 1		74°F	72.5	4748
4699	30 mph	.15	1.52	747	.84	13.6	DF 2		67.5°F	63	4505
4700	60 mph	.15	.31	656	1.20	15.5	DF 2		73°F	69.5	4692*
4701	30 mph	.19	1.35	844	1.04	12.0	DF 2		71°F	69.5	4879*
4702	60 mph	.14	.40	719	1.43	14.1	DF 2		76°F	74	5065
4725	30 mph	1.35	1.74	901	1.00	11.2	DF 2		70.5°F	64	5300*
4726	60 mph	1.53	.79	766	1.53	13.2	DF 2		73°F	69.5	5393
4773	30 mph	1.02	1.31	680	.75	12.9	Gasoline		70.5°F	72.5	4002*
4774	60 mph	1.11	.57	557	1.12	15.8	Gasoline		77°F	80.5	3922
4832	30 mph	.72	1.31	696	.84	12.7	Gasoline		71°F	71	4042*
4833	60 mph	.66	.51	550	1.03	16.0	Gasoline		74°F	77	3962*

* Estimated Air Flow.

TABLE IV
FUEL ECONOMY TESTS

SPEED MPH	HORSEPOWER	COMPRESSOR RPM	COMPRESSOR INLET TEMPERATURE °F	REGENERATOR INLET TEMPERATURE T8 °F	FUEL ECONOMY MPG
15	.9	21,000	72	1055	10.4
30	3.1	22,500	69	1218	16.3
	3.0	22,500	69	1218	16.3
	2.9	22,500	69	1218	16.3
	3.1	22,500	70	1218	15.7
	3.5	22,500	72	1225	15.7
	3.2	24,000	72	1233	14.0
	3.3	23,500	72	1233	15.1
	3.4	24,000	74	1235	14.4
45	10.4	27,700	66	1205	14.4
	10.2	26,750	71	1250	16.1
	10.2	26,750	70	1275	16.0
	10.0	27,750	73	1227	14.9
	9.8	28,000	73	1227	14.3
	10.0	27,800	73	1225	15.1
	10.0	27,750	73	1225	15.1
60	23.1	31,500	75	1315	13.2
	22.4	31,500	75	1315	13.2
	22.3	32,000	69	1275	13.1
	22.3	32,000	69	1275	13.2
	23.9	32,000	69	1275	13.3
	21.5	31,500	74	1290	13.2
	21.4	31,500	74	1285	13.8
	21.4	31,500	74	1285	13.8
	21.4	31,500	74	1287	13.8
	22.0	30,750	68	1225	14.8
	22.5	30,750	70	1225	14.6
75	37.5	34,250	74	1368	12.0
	37.6	34,250	74	1367	12.0
	37.6	34,250	75	1372	12.0

TABLE V
SULFUR DIOXIDE LEVELS

Sample Number	Fuel Consumption gal/hr.	Measured SO_2, ppm
1	3.78	11.2
2	3.88	10.6
3	4.45	10.1
4	4.63	9.8
5	4.68	9.5
6	5.04	9.2
7	5.29	9.0

Test Conditions

60 mph
270 ft. lbs. torque at rear wheels (21.6 horsepower)
Fuel - Diesel No. 1, 6.79 lbs./gallon
.2% Sulfur ± .01% by weight

CO_2 1.20% measured in tailpipe

Estimated Sulfur in Exhaust

$\dot{M}$ Sulfur = % S x $\dot{M}$ Fuel = .002 x $\dot{M}f$ $\dot{M}s$ mass flow rate

$\dot{M}$ Carbon = % C x $\dot{M}f$ = .86 x Mf

$$\dot{M}\text{oles Sulfur} = \frac{\dot{M}s}{\text{Atomic Wt. S}} \times K = \frac{\dot{M}s \times K}{32} \qquad K = \text{constant}$$

$$\frac{S}{C}\ \text{Ratio} = \frac{.002 \times \dot{M}f \times K}{32} \Big/ \frac{.86 \times \dot{M}f \times K}{12} = \frac{1}{1153}$$

% Carbon in exhaust = % CO_2 in exhaust

Sulfur concentration ≑ % CO_2 ÷ 1153 = 1.2% ÷ 1153 = 10.4 ppm as S, SO_2, SO_3, etc.

TABLE VI

AMBIENT HYDROCARBON EFFECTS

Speed, mph	Inlet Air HC Level Above Background ppm C_3	Exhaust Sample, ppm C_3	Net Change, ppm C_3	Test Date
30	12	5.2	1.0	7/13/74
	Standard	4.2		
	Standard	2.2		
	9.5	4.2	2.0	
	.4	2.5	1.2	
	Standard	1.3		
45	Standard	.5		
60	Standard	.3		
	3.6	.3	.0	
	6.8	.3	.0	
	9.8	.7	.4	

Sample Taken From Vehicle Exhaust

AMBIENT NOx EFFECTS

Speed, mph	Inlet Air NOx Level Above Background ppm	Exhaust Sample, ppm	Net Change, ppm	Test Date
60	1.5	33.3	4.0	7/13/74
	Standard	29.3		
	.4	29.5	.0	
	Standard	29.6		
	.8	31.1	.5	
	Standard	19.7		
	.4	19.9	.2	

Sample Taken From Vehicle Exhaust

Note: Variation in exhaust emission levels with time during the test is accounted for in calculating Net Change.

TABLE VI - Continued

AMBIENT CO EFFECTS

Speed, mph	Inlet Air CO Levels Above Background, ppm	Exhaust Sample, ppm	Net Change, ppm	Test Date
30	Standard	43.		6/29/74
	6.6	48.6	5.6	
	3.6	44.9	.9	
	1.2	40.2	-4.2	
	Standard	44.4		
	Standard	39.5		
45	Standard	81.0		7/13/74
	Standard	89.2		
	1.8	78.9	-1.4	
	Standard	81.3		
	1.2	81.8	.6	
	Standard	81.0		
	5.4	83.9	2.8	
	Standard	81.1		
	3.6	82.5	1.4	
60	Standard	17.0		6/29/74
	6.5	19.7	2.7	
	9.9	21.0	4.0	
	2.5	17.3	1.9	
	2.9	17.2	1.8	
	Standard	15.4		
	Standard	37.0		7/13/74
	3.0	36.7	.1	
	Standard	36.2		
	2.5	36.9	1.1	
	Standard	35.4		
	9.9	41.7	6.0	
	Standard	35.9		
	6.5	39.0	2.6	
	Standard	36.9		

Samples Taken From Vehicle Exhaust

Note: Variation in exhaust emission levels with time during the test is accounted for in calculating Net Change.

Table VII
Odor Test Conditions and Results

Test Condition	MPH	Load	Gear	Obs. Whl. HP	Fuel Flow #/Hr	T/C Input RPM	Odor Ratings: No. of Samples	D	B	O	A	P	Gaseous Emissions: No. of Samples	HC PPM_C	CO PPM	NOx PPM	CO_2 %
Cold Start[I]	0	-	P	-	-	-	7	3.7	1.1	0.9	0.6	0.9	1	376	93	10	2.07
Hot Start[I]	0	-	P	-	-	-	9	1.3	0.7	0.3	0.3	0.1	6	33	60	6.5	0.70
Idle	0	-	P	-	10.5	633	9	1.5	0.7	0.4	0.4	0.2	6	37	62	7.5	0.70
Intermediate Speed	16	Nil	D-1	-	10.7	1415	9	1.3	0.8	0.4	0.3	0.1	5	27	46	10.2	0.77
Intermediate Speed	33	2xRL	D-3	8.5	17.1	1272	9	1.1	0.7	0.3	0.3	0.1	5	19	42	12.6	1.00
Intermediate Speed	30.5	4xRL	D-3	14.5	21.6	1272	9	1.1	0.7	0.4	0.2	0.1	5	15	22	17.8	1.12
High Speed	59	Nil	D-3	-	16.3	2120	9	1.0	0.6	0.2	0.2	0.1	6	19	28	14.4	1.05
High Speed	58	2xRL	D-3	33	32.5	2120	9	1.0	0.7	0.2	0.1	0.1	5	21	12	36.7	1.42
High Speed	56	4xRL	D-3	66	55	2120	9	1.2	0.7	0.4	0.3	0.1	6	49	11	63.1	1.68
Idle - Accel.[II]	0-20	4000	D-1	-	-	-	9	0.8	0.5	0.2	0.2	0.1	-				
Accel.[III]	25-55	4000	D-3	-	-	-	9	0.8	0.5	0.2	0.2	0.1	-				
Deceleration[IV]	50-35	4000	D-3	-	-	-	9	0.9	0.6	0.2	0.2	0.1	-				
Relight[V]	50-30	4000	D-3	-	-	-	9	0.8	0.5	0.2	0.1	0	-				

I Sniff at end of automatic start cycle.
II WOT - Sniff at 15 MPH.
III WOT - Sniff at 50 MPH.
IV Closed throttle - Sniff at 42 MPH, before relight.
V Closed throttle - Sniff at relight

Figure 2

TABLE VIIIa
SOUND LEVELS

SAE J986a Drive-By Test

	Vehicle's Left Side Decibels	Vehicle's Right Side Decibels
Run 1	74	71
Run 2	72	71
Average	73	71

SAE J986a Drive-By Test, Discrete Frequencies

Frequency (Hertz)		
125 HZ	78	76
	80	75
250 Hz	71	72
	71	71
500 Hz	72	71
	73	71
1000 Hz	74	70
	72	68
2000 Hz	64	62
	61	61

TABLE VIIIb

SAE J986a Drive-By Test, Discrete Frequencies*

125	82	76
	76	77
	78	
250	73	74
	75	74
500	72	72
	73	72
1000	68	68
	68	67
2000	60	60
	62	60

* Procedure modified: Vehicle accelerated wide open throttle from stop instead of wide open throttle from 30 mph.

TABLE IX
VEHICLE GRADEABILITY

MPH	%GRADE	HORSEPOWER	COMPRESSOR RPM*	COMPRESSOR INLET TEMPERATURE T8 °F	REGENERATOR INLET TEMPERATURE °F	MPG
0			32,000	Exceeded Dyno Capacity		
5	30%	18				
30	14.6%	56	39,000	65	1305	3.4
	14.6%	56	39,000	65	1305	3.5
60	6%	65	39,000	75	1330	6.9

* Test restricted to 39,000 RPM

ESTIMATED VEHICLE ROAD LOAD
AT REAR WHEELS

MPH	HORSEPOWER*
10	.07
20	1.0
30	3.3
40	7.3
50	13.2
60	23.4
75	37.5

* From Manufacturers engine data.
Transmission and rear wheel losses estimated.

FLOW CALCULATION

For exhaust ducts

$$\text{moles } CO_2 = \frac{\text{Fuel wt. (gms)}}{13.97 \text{ gm/mole}}$$

$$\%CO_2 = \frac{\text{moles } CO_2}{\text{moles exhaust}}$$

$$\text{moles exhaust/hr} = \frac{\text{fuel wt. (gm/hr.)}}{13.97 \text{ (gm/mole) x } \%CO_2}$$

$$\text{Volume exhaust/hr.} = \frac{\text{moles exhaust}}{\text{hr.}} \quad \frac{\text{volume}}{\text{mole}}$$

$$= \frac{\text{fuel wt. (gm/hr)}}{13.97 \text{ (gm/mole) x } \%CO_2} \text{ x } \frac{22.4 \text{ liters}}{\text{mole}} \text{ x } \frac{460 + \text{FTP}}{460 + 32}$$

= exhaust velocity x duct area $\quad T_p$ = Tailpipe temperature

therefore for exhaust ducts:

$$\text{velocity} = \frac{\text{Volume}}{\text{area}} \quad \frac{\text{(cubic ft/hr)}}{\text{square ft}}$$

for sample pump

cubic feet/hr. = velocity x pipe area

$$\text{standard cubic ft./hr.} = \text{cubic ft./hr.} \quad \frac{530}{460 + F_p}$$

sample pump flow rates are adjusted so that sample flow equals duct flow. This is required for isokinetic sampling.

Definitions of Driveability Terms

1. Road Load -- A fixed throttle position which maintains a constant vehicle speed on a level road.

2. Wide Open Throttle (WOT) Acceleration -- An acceleration made entirely at wide open throttle (from any speed).

3. Part Throttle (PT) Acceleration -- An acceleration made at any throttle position less than WOT.

4. Tip-In -- A maneuver to evaluate vehicle response (up to two seconds in duration) to the initial opening of the throttle.

5. Crowd* -- An acceleration made at a constant intake vacuum (continually increasing throttle opening).

6. Idle Quality -- An evaluation of vehicle smoothness with the engine idling, as judged from the driver's seat.

7. Backfire -- An explosion in the induction or exhaust system.

8. Hesitation -- A temporary lack of initial response in acceleration rate.

9. Stumble -- A short, sharp reduction in acceleration rate.

10. Stretchiness -- A lack of anticipated response to throttle movement. This may occur on slight throttle movement from road load or during light to moderate accelerations.

11. Surge* -- A continued condition of short, sharp fluctuations in power. These may be cyclic or random and can occur at any speed and/or load. Surge is usually caused by over-lean carburetor mixtures.

12. Trace -- Rating of a malfunction that is just discernible to a test driver.

13. Moderate -- Rating of a malfunction that is judged to be probably noticeable to the average driver.

14. Heavy -- Rating of a malfunction that is pronounced and judged to be obvious to any driver.

* Not applicable to gas turbine engine