EXHAUST EMISSIONS FROM A 25 - PASSENGER INTERNAL COMBUSTION ENGINE POWERED GASOLINE FUELED BUS

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Background

Under a grant from the U.S. Department of Transportation, LTV Aerospace of Dallas will install a Rankine cycle power system, built by Sundstrand Aviation, in a 25-passenger city bus for use in the Dallas public transit system. The bus chosen for this project is a Twin Coach built by Highway Products, Inc. of Kent, Ohio. The engine usually installed in the bus is a gasoline fueled V8 internal combustion engine.

The Test and Evaluation Branch will test the bus when the Rankine system installation is completed and it was necessary to test the conventionally powered bus in order to establish "baseline" emissions, with which the Rankine system emissions could be compared.

Vehicle Tested

The vehicle was a Twin Coach 25-passenger city bus powered by a 413 C.I.D. Chrysler V8 engine burning gasoline. The engine was mounted in the rear and drove the rear wheels through an automatic transmission. The engine had positive crankcase ventilation, but no other emission control technique was in evidence.

The normal curb weight of the bus is about 10,500 pounds. The bus we tested was somewhat lighter, since none of the passenger seats had been installed.

Test Program

The bus was delivered to the Willow Run laboratory on Monday, September 13, 1971. Engine trouble delayed testing until Friday, September 17.

For these tests a simulated inertia weight of 5500 pounds, the maximum available on the Clayton two-roll dynamometer, was used. All emissions tests employed the Constant Volume Sampling method. Operating conditions used were the Ann Arbor-1 (AA-1) Urban Bus Cycle, steady state modes, and an approximation of the CARB-EMA Diesel Emissions Test Procedure.

Normal analysis methods were employed: FID for unburned hydrocarbons, NDIR for CO and CO_2, and chemiluminescence (C.L.) for NOx.

The AA-1 Bus Route was developed by EPA for this project and is an actual speed versus time trace generated using a fifth wheel on one of the busses of the Ann Arbor Transportation Authority. It can be and was used with either a hot or cold start. The modes used for the steady state tests were idle, 15, 25, and 35 mph cruises, each maintained for two to five minutes to allow time for an adequate sample to be collected.

The CARB-EMA Diesel procedure used is described in SAE paper number 700671. It is a steady state procedure for testing a Diesel engine on an engine dynamometer with engine load as the operating variable at each of two engine speeds, "Rated" and "Intermediate." The load is varied from zero to maximum torque available at the particular engine speed, in steps of 25% of maximum torque. Three idle periods are interspersed among these load points, for a total of 13 operating modes.

From data supplied by Mr. J.M. Nunez of Chrysler (who was contacted for us by Mr. David Randolph of LTV) it was determined that Rated speed for the 413 engine was 3200 rpm. The Intermediate speed is defined in the Diesel procedure as "Peak torque speed or 60% of rated speed, whichever is higher." On the Chrysler 413, peak torque occurs at 2000-2100 rpm, so 2000 rpm was used as the Intermediate speed.

The engine loads at each speed were based on the estimated output of the Rankine system, which information was acquired from Sundstrand. The Rankine system will deliver to the wheels a maximum of 70 hp at its Rated speed and 50 hp at 60% of its Rated speed.

The procedure for our 13-mode tests was to establish the desired engine speed with the transmission engaged and the chassis dynamometer water brake fully unloaded. In this condition the dynamometer still absorbed 7 hp because of internal friction. After sufficient time in this mode for collection of an adequate sample of the diluted exhaust gas, the water brake load was then increased to 25%, 50%, 75%, and 100% of the maximum power at the chosen engine speed, with bag samples collected at each condition. The idle

modes were run with the transmission engaged and the bus brakes on to prevent creeping. Power absorption limitations prevented us from running in the 70 hp @ 3200 rpm mode.

In addition to the emissions test a simple exterior noise test was conducted using the SAE Recommended Practice J366, for full throttle acceleration only. Two runs were made in each direction. The closed throttle deceleration test was not run.

Results

Mass emissions are reported here in grams per minute for the 13-mode tests. Specific mass emissions in grams per rear wheel horsepower-hour have also been calculated. Data from the AA-1 bus route tests is presented in grams per mile. The length of the bus route was estimated to be eight miles. From the steady state tests the data is presented in both grams per minute and grams per mile.

Data from the bus route tests are presented in Table 1. Emissions of CO_2 are included to indicate fuel consumption. The variability of CO_2 emissions was greater than normally experienced, and the variability of HC and NOx emissions was less than expected, considering the apparent condition of the engine.

Quite early in our testing a random knocking noise was heard in the engine. Informal diagnosis by our experienced technicians was that the noise was due to problems in the valve train of one of the cylinders. The bus was taken, at the suggestion of Chrysler, to the Continental-Kromis engine repair center, which specialize in Chrysler engines. It was returned two days later with a report that the engine was okay. The tests and the knocking continued, with an intermittent miss developing soon after. The knock and the miss disappeared when the engine was heavily loaded.

Data from the steady state tests are presented in Table 2. On the basis of grams per mile there was little change in emissions when speed was increased, except for the HC emissions. The increase in road load power from 15 mph to 35 mph was apparently not enough to affect NOx emissions greatly. The CO_2 emissions, in grams per mile, decreased about 10% when cruise speed was increased from 15 mph to 25 or 35 mph.

Listed in Tables 3 and 4 are the results from the 13-mode tests. Table 3 presents emissions in terms of grams per minute. The Intermediate speed data are fairly repeatable. Repeatability of the Rated speed data is poor, except for NOx emissions. The mass emissions in Table 4 are in terms of grams per rear-wheel horsepower-hour. The efficiency of the drive train was not known so it was not possible to calculate brake horsepower.

The arithmetic average of four noise tests, two in each direction, was 83 dBA. See Table 5. Runs 1 and 3 were in one direction, with the bus radiator on the opposite side of the bus from the microphone, and were 2 dBA lower than the runs in the opposite direction with the radiator on the same side as the microphone.

Conclusions

These tests of a gasoline-powered bus were of value to the T&E Branch mainly for the experience of testing a large vehicle at high engine loads. The value of the emissions data is suspect because significant test conditions were not as they should have been. Because the data are probably not suitable even as a rough approximation of baseline for this bus, additional baseline tests are pla-ned when these limitations are overcome.

Among the conditions that gave rise to questionable data were the following:

- The simulated inertia weight was only 5500 pounds, while the actual bus weight is about 10,500 pounds. Thus, CO_2 and NOx emissions were certainly lower than they should be.
- Because of power absorption limitations we were not able to test the maximum load at Rated speed.
- The bus was new, with only about 500 to 600 miles on the odometer. Thus the engine was probably still in a break-in period and the emissions were probably not typical of the same engine when broken in.
- The intermittent knocking and misfiring condition of the engine should not be considered typical or baseline, and probably had a detrimental effect on emissions.
- It was not known whether the engine timing and carburetion conformed to the manufacturer's specifications.

It would be valuable to conduct a similar series of tests in the future, using an adequate chassis dynamometer, on a Diesel-powered bus as well as a properly operating gasoline powered bus.

Table 1

25-Passenger Gasoline Powered Bus
Mass Emissions

Ann Arbor -1 Bus Route

Grams per mile

Date	HC	CO	CO_2	NOx	Comments
9-17	22.09	100.10	1035.6	10.23	Cold Start
9-20	25.77	130.29	1145.5	11.52	Cold Start
9-23	25.31	97.80	962.8	10.73	Cold Start
9-24	23.75	91.82	1068.91	11.57	Cold Start
9-20	22.63	115.77	1049.83	11.66	Hot Start
9-21	23.85	101.55	1003.09	11.58	Hot Start
9-23	25.09	109.87	1064.98	11.54	Hot Start

Table 2

25-Passenger Gasoline Powered Bus
Mass Emissions

Steady State Modes

Mode	Date	Grams per minute HC	CO	CO_2	NOx	Grams per mile HC	CO	CO_2	NOx
Idle	9-20	3.70	9.09	93.15	.12	Not applicable			
Idle	9-21	3.65	4.35	103.26	.11	Not applicable			
15 mph	9-20	9.36	17.52	257.5	.65	37.44	70.08	1030.0	2.60
15 mph	9-21	9.00	15.89	220.1	2.42	36.00	63.56	880.4	9.68
15 mph	9-23	off scale	15.5	243.3	2.61	off scale	62.0	973.2	10.44
25 mph	9-20	12.83	32.26	373.3	5.06	30.79	77.42	895.9	12.14
25 mph	9-21	13.07	25.05	365.7	4.87	31.37	60.12	877.7	11.69
25 mph	9-23	off scale	23.71	335.7	4.54	off scale	56.90	805.7	10.90
35 mph	9-20	5.48	off scale	524.7	7.42	9.39	off scale	899.5	12.72
35 mph	9-21	6.46	46.62	510.2	6.44	11.07	79.92	874.6	11.04
35 mph	9-23	7.41	43.99	472.7	5.79	12.70	75.41	810.3	9.93

Table 3

25-Passenger Gasoline Powered Bus
Mass Emissions

CARB-EMA 13-Mode
Diesel Engine Test Procedure

Grams per minute

Mode	Date	HC	CO	CO_2	NOx
Idle	9-23	2.91	10.61	109.95	.15
Idle	9-23	3.58	4.36	91.97	no data
Idle	9-24	3.40	4.10	92.85	.16
7 hp@2000 rpm	9-23	8.91	35.20	457.94	6.24
7 hp@2000 rpm	9-23	9.16	34.41	428.20	5.28
7 hp@2000 rpm	9-24	3.36	31.90	446.63	6.89
13 hp@2000 rpm	9-23	6.38	39.76	464.30	7.06
13 hp@2000 rpm	9-23	6.15	38.41	436.41	5.99
25 hp@2000 rpm	9-23	2.73	off scale	562.05	9.66
25 hp@2000 rpm	9-23	3.04	off scale	550.49	9.02
25 hp@2000 rpm	9-24	2.47	47.12	530.16	10.47
tp@2000 rpm	9-23	6.59	48.15	off scale	off scale
38 hp@2000 rpm	9-23	2.42	off scale	588.21	11.20
50 hp@2000 rpm	9-23	2.34	45.49	686.40	off scale
50 hp@2000 rpm	9-24	2.56	off scale	674.93	12.78
Idle	9-23	3.13	5.70	92.63	.07
Idle	9-23	2.76	9.27	130.0	.23
Idle	9-24	2.18	5.95	107.16	.39
7 hp@3200 rpm	9-23	3.65	off scale	714.69	12.45
7 hp@3200 rpm	9-24	2.79	49.53	619.55	12.18
18 hp@3200 rpm	9-23	3.11	off scale	752.74	14.48
18 hp@3200 rpm	9-24	2.18	47.09	591.72	12.76
35 hp@3200 rpm	9-23	3.33	off scale	867.07	off scale
35 hp@3200 rpm	9-24	1.78	35.88	574.07	13.94
53 hp@3200 rpm	9-23	3.70	off scale	off scale	off scale
Idle	9-23	2.22	10.93	110.33	.23
Idle	9-24	1.84	4.48	80.48	.28

Table 4

25 - Passenger Gasoline Powered Bus
Mass Emissions

CARB-EMA 13-Mode
Diesel Engine Test Procedure

Grams per rear wheel horsepower-hour

Mode	Date	HC	CO	CO_2	NOx
7 hp @ 2000 rpm	9-23	76.4	301.7	3925.2	53.49
7 hp @ 2000 rpm	9-23	78.5	294.9	3670.3	45.26
7 hp @ 2000 rpm	9-24	28.80	273.4	3828.3	59.06
13 hp @ 2000 rpm	9-23	29.45	183.5	2142.9	32.58
13 hp @ 2000 rpm	9-23	28.38	177.3	2014.2	27.65
25 hp @ 2000 rpm	9-23	6.55	off scale	1348.9	23.18
25 hp @ 2000 rpm	9-23	7.30	off scale	1321.2	21.65
25 hp @ 2000 rpm	9-24	5.93	113.1	1272.4	25.13
38 hp @ 2000 rpm	9-23	10.41	76.03	off scale	off scale
38 hp @ 2000 rpm	9-23	3.82	off scale	928.7	17.68
50 hp @ 2000 rpm	9-23	2.81	54.59	823.7	off scale
50 hp @ 2000 rpm	9-24	3.07	off scale	809.9	15.34
7 hp @ 3200 rpm	9-23	31.29	off scale	6125.9	106.7
7 hp @ 3200 rpm	9-24	23.91	424.5	5310.4	104.4

Table 4 continued

Mode	Date	HC	CO	CO_2	NOx
18 hp @ 3200 rpm	9-23	10.37	off scale	2509.1	48.27
18 hp @ 3200 rpm	9-24	7.27	157.0	1972.4	42.53
35 hp @ 3200 rpm	9-23	5.71	off scale	1486.4	off scale
35 hp @ 3200 rpm	9-24	3.05	61.51	984.1	23.90
53 hp @ 3200 rpm	9-23	4.19	off scale	off scale	off scale

Table 5

25 - Passenger Gasoline Powered Bus

Noise Tests
per
SAE RP J366
Full Throttle Acceleration

Run No.	Noise Level
1	82 dBA
2	84 dBA
3	82 dBA
4	84 dBA