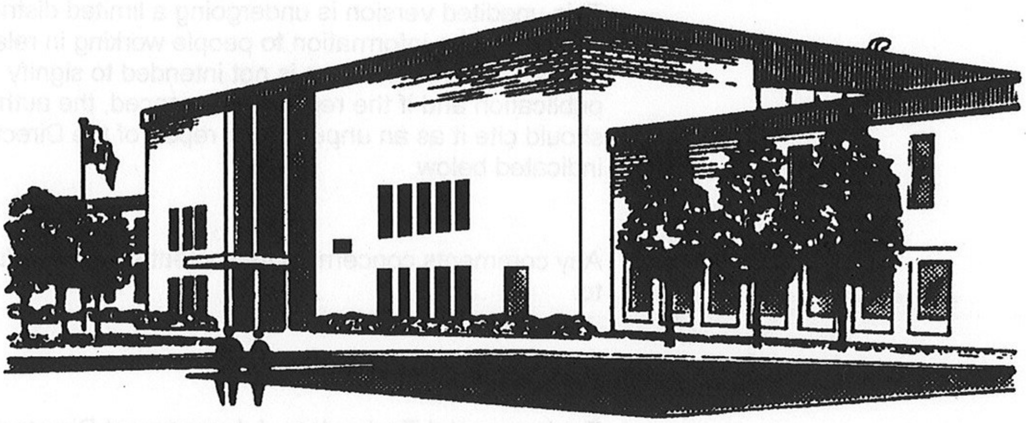
Emissions Evaluation of Orion VII Hybrid Bus with BAE Systems Controls HybriDrive™ Propulsion System



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EXECUTIVE SUMMARY

The exhaust emission rates of selected components were determined for the Orion VII hybrid diesel electric powered urban transit bus over the Central Business District (CBD) transient driving cycle.

Emissions were measured in order to validate the BAE SYSTEMS Controls HybriDrive™ Propulsion System control strategy on NO_x production and to determine emission rates using various particulate traps and fuel configurations. Five particulate traps were tested with an ultra low diesel fuel (<30 ppm sulphur); two of the traps were also tested using low sulphur diesel fuel (~380 ppm sulphur). The bus emissions were also tested in a baseline configuration with a straight exhaust pipe installed in place of the particulate trap and ultra low sulphur diesel fuel.

The exhaust emission tests were conducted on a heavy-duty chassis dynamometer capable of simulating the inertia weight and road loads that urban buses are subjected to during normal on-road operation. This collaborative evaluation was undertaken with support from Orion Bus Industries. Other project partners included; BAE SYSTEMS Controls and Cummins Inc.

The emissions of total hydrocarbons (THC), carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_x), nitrogen dioxide (NO_2), and total particulate matter (PM) were determined for the Orion VII hybrid bus over the CBD cycle. Carbon dioxide (CO_2) was also measured and fuel economy was calculated based on a carbon balance equation. The bus was also driven over a simulated New York City transit bus driving route at different ambient temperatures (24°C, 0°C, and −15°C). Engine and exhaust temperatures were recorded to determine the effect of the control strategy at varying ambient temperatures.

With the hybrid diesel electric vehicle the engine reacts not only to the vehicle loads but also to the battery state of charge (SOC); therefore, the engine is not necessarily load following. Without the state of charge correction, the emission results were not consistent from test to test and therefore all of the individual emission test results were reported as opposed to an average, with the exception of two configurations. The emission rates from two particulate traps, NEX 0311-5 and NEX 0311-50, were corrected for SOC as these are the particulate traps that Orion Bus intends to use in production.

The results of the testing demonstrated significant reductions in the emissions of CO, THC and PM with all of the traps installed compared to the baseline configuration. In general, the emission rates for all traps achieved the 15.0 g/mile NO_x emission rate and the 0.06 g/mile PM emission rate limit without SOC correction. The average SOC corrected results from the NEX 0311-5 with LSD and the NEX 0311-50 with ULSD for NO_x and PM were below 15.0 g/mile and 0.06 g/mile respectively.

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1.0 INTRODUCTION

Over the past few years the emissions from urban transit buses have been considered a significant source of ambient air pollutants such as particulate matter and oxides of nitrogen. These vehicles are quite visible to the urban population and hence their emissions of smoke and other odorous compounds are perceived as obvious contributors to urban air quality problems. In recent years stringent emission standards have been introduced which limit the emission rates from new engines[1]. Emission limiting legislation for in-service urban bus[2] engines was implemented in the United States in 1994.

Engine manufacturers have been investigating a number of options in the areas of engine design, fuel management, exhaust aftertreatment, and alternative fuels, to reduce emissions from new engines to the levels dictated by legislation. For the in-use segment of heavy duty engine applications, the potential emission reduction opportunities which have been investigated include retrofit exhaust aftertreatment systems such as diesel catalytic converters and particulate traps. Bus manufacturers are in the unique situation where they can develop vehicles that implement these techniques.

From the perspective of the transit operator, a bus that has lower emissions of harmful pollutants is desirable due to fewer complaints from the public coupled with a greater overall acceptance of the vehicles. However, economics is also an important factor in public transportation, particularly with the trend toward reductions in government subsidies. Therefore, the engines which are powering urban buses must have low emissions, high fuel economy, as well as a high degree of durability and serviceability. With the heavy duty hybrid diesel electric vehicle the goal is to optimize the internal combustion engine within a narrow performance range and thus improve emissions and fuel economy by storing and releasing electrical energy in the batteries.

In this study, the Emissions Research and Measurement Division (ERMD) of Environment Canada, conducted exhaust emission tests on an urban transit bus manufactured by Orion Bus Industries with a HybriDrive™ Propulsion System developed by BAE SYSTEMS Controls. The following report describes the procedures and results of the emissions testing program.

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[1] USEPA Code of Federal Regulations Schedule 40 Part 86, July 1st 1996

[2] USEPA Federal Register Vol. 62. No. 20 FRL-5682-4, January 1997

2.0 TEST PROGRAM

The following sections describe the test program including the vehicle, device and fuels used, the test facility, drive cycles, and the test procedures.

Vehicle Description

The test vehicle was the Orion VII Hybrid Bus and details of the vehicle are provided in Table 1.

Table 1. Test Vehicle Specications

Component	Specification
Vehicle Length	40 feet
Vehicle Width	102 inches
Vehicle Height	132 inches
Engine	Cummins ISB 270 hp
Generator	BAE SYSTEMS Controls 120 kw
Battery Pack	46 Hawker Lead Acid Batteries
Seat Capacity	40
Curb Weight (full fuel)	31350 lb

Device Configurations

A total of 5 particulate traps were testing in this program. Two of the traps were tested with both LSD and ULSD fuel. One trap was tested with the control strategy forced ON or OFF. Table 2 lists the test matrix. The last two devices listed in the table are the particulate traps that Orion Bus intends to use in production depending on the type of diesel fuel available.

Table 2. Test Matrix

Device	Fuel		Configuration
Baseline (Straight Pipe)	ULSD		
JMI CRT (improved)	ULSD		
MEX 003-50 (internal cone)	ULSD		
MEX 003-50 (internal cone)	ULSD		Controls ON / A/C ON
MEX 003-50 (internal cone)	ULSD		Controls OFF/ A/C OFF
MEX 003-50 (internal cone)	ULSD		Controls ON / A/C OFF
MEX 003-2		LSD	
NEX 0311-5	ULSD	LSD	
NEX 0311-50	ULSD	LSD	

A/C = Air Conditioning

ULSD = Ultra Low Sulphur Diesel fuel provided by Cummins Inc. with a specified maximum sulphur level of 30 ppm.

LSD = Low Sulphur Diesel (Certified Diesel Type 1-D) provided by Environment Canada with a sulphur level of 380 ppm.

Facility and Equipment Description

- ***Gaseous Emissions Measurement***

The total exhaust stream produced by the bus was collected and diluted using a constant volume sampling (CVS) dilution system with a total nominal dilute exhaust volume of 2000 scfm. The dilution air was taken from the test cell and was conditioned only by removal of particulate matter using HEPA filtration. The total volume of raw exhaust was transferred from the bus to the CVS through a flexible stainless steel pipe. The raw exhaust was then diluted with laboratory background air and the mixture drawn through a critical flow venturi. During the exhaust emissions test, continuously proportioned samples of the dilute exhaust mixture and the dilution air were collected and stored in Tedlar™ sample bags for analysis. Concurrently dilute exhaust concentrations were also logged on a second by second continuous basis.

Gaseous samples were analyzed for the concentrations of total hydrocarbons (THC), oxides of nitrogen (NO_X), nitric oxide (NO), carbon monoxide (CO), and carbon dioxide (CO_2). THC, NO_x and NO concentrations were determined on a continuous basis during the testing by drawing a sample of the dilute exhaust through a heated probe, heated filter, and heated sample line to a heated flame ionization detector, for THC, and to two heated chemiluminescence detectors, for NO_x and NO. Concentrations of nitrogen dioxide (NO_2) were determined by subtracting nitric oxide (NO) measurements from NO_X, assuming the sum of NO_X was NO plus NO_2.

Another probe located in the same area of the heated probe was used to direct a sample of the exhaust to two non-dispersive infrared detectors (NDIR) used to continuously measure concentrations of CO and CO_2.

For all tests with particulate traps the concentrations of CO were at the detection limits of the NDIR. Therefore, sample bags of the dilute exhaust and dilution air were collected and were analyzed by gas chromatography for CO concentrations.

- ***PM Emissions Measurement***

An isokinetic particulate sampling system directed the exhaust through Pallflex T60A20 filters (Teflon coated glass fiber) which were used to collect particulate mass from the sample stream. A gravimetric method, as outlined below, was used to determine the particulate mass.

Prior to testing, all filters were stored in a desiccator where the conditions were maintained at 40±10% humidity and 24°C. After this stabilization period, the filters were weighed on a Mettler AE240. The filters were then stored in covered Petri dishes and remained in the desiccator until needed for testing. The filters were removed from the desiccator just prior to commencing the testing and were placed in a sealed stainless steel filter holder assembly located downstream of the dilution tunnel. After the test, the filters were re-stabilized in the desiccator for 12-24 hours and re-weighed to determine the net mass of diesel particulate emissions.

- *Chassis Dynamometer Description*

The bus was driven over a single roll chassis dynamometer system with a 0.6096m (24 inch) diameter roll. The inertia weight and road load were simulated during testing using a 400 Hp General Electric direct current motor. The system has the capability of testing vehicles from 7700 to 35000 kg (16940 to 77000 lb) with the road load simulated at all vehicle speeds while compensating for the systems internal power losses. The Orion VII was tested at an inertia weight of 15682 kg (34500 lb) and a road load of 56.2 Hp.

The rotating speed of the dynamometer roll during a vehicle emissions test is measured by a pulse counter, which transfers the data to a microprocessor controller. The controller translates the pulses into the linear speed of the vehicle which is displayed on a video screen as a cursor. The vehicle driver then uses the cursor to follow a selected speed versus time trace. In this manner, the vehicle may be operated over a selected transient operation or driving cycle.

BAE SYSTEMS Controls technical representatives conducted on road vehicle coast downs before the vehicle was delivered to the ERMD. The coast downs were then repeated on the ERMD chassis dynamometer. Figure 1 illustrates the target loading curve for the bus. The upper target curve is generated from the coast down data supplied by BAE SYSTEMS Controls. The actual dynamometer setting curve is the resulting curve from matching the on road coast down times to those coast downs performed on the dynamometer. The difference of approximately 50 road load horsepower at 50 mph represents the parasitic losses in the drive train of the bus and the wheel to roll interference losses. This figure is consistent with previous road load determinations conducted in the past.

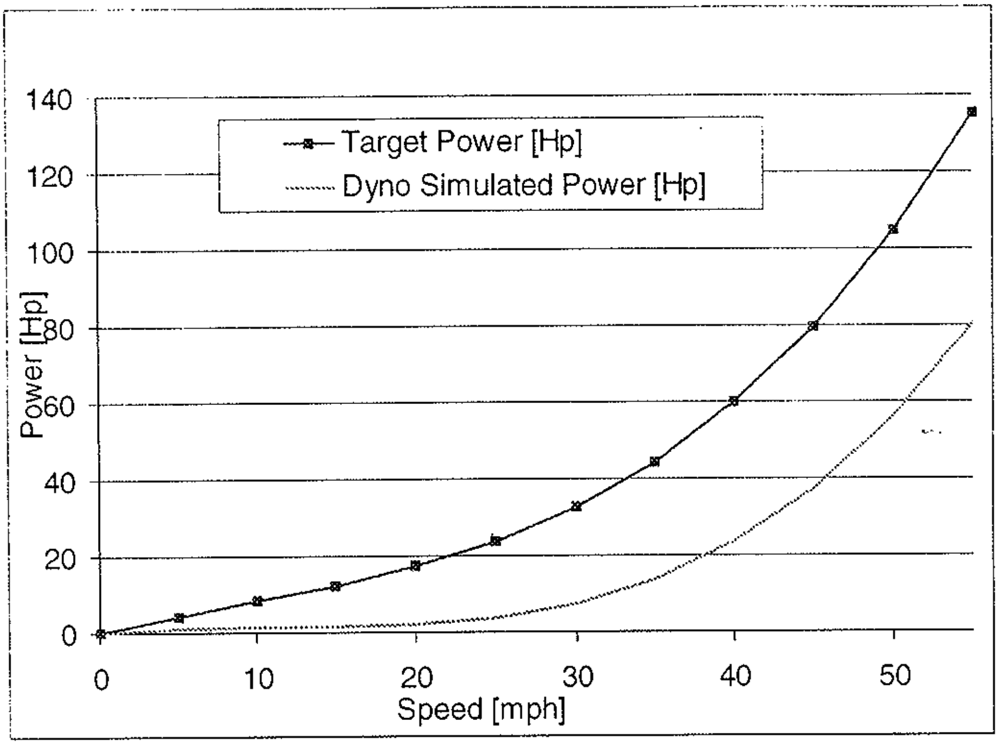

Figure 1. Orion Hybrid VII Bus Target Loading Curve

Driving Cycles

The Central Business District (CBD) Cycle is a chassis dynamometer testing procedure for heavy-duty vehicles (*SAE J1376*). The CBD cycle represents a "sawtooth" driving pattern, which includes 14 repetitions of a basic cycle composed of idle, acceleration, cruise, and deceleration modes. The following are characteristic parameters of the cycle:

- Duration: 574 s
- Average speed: 20.23 km/h (12 mph)
- Maximum speed: 32.18 km/h (20 mph)
- Driving distance: 3.23 km (2.05 miles)
- Average acceleration: 0.89 m/s^2
- Maximum acceleration: 1.79 m/s^2

Vehicle speed over the duration of the CBD cycle is shown in Figure 2.

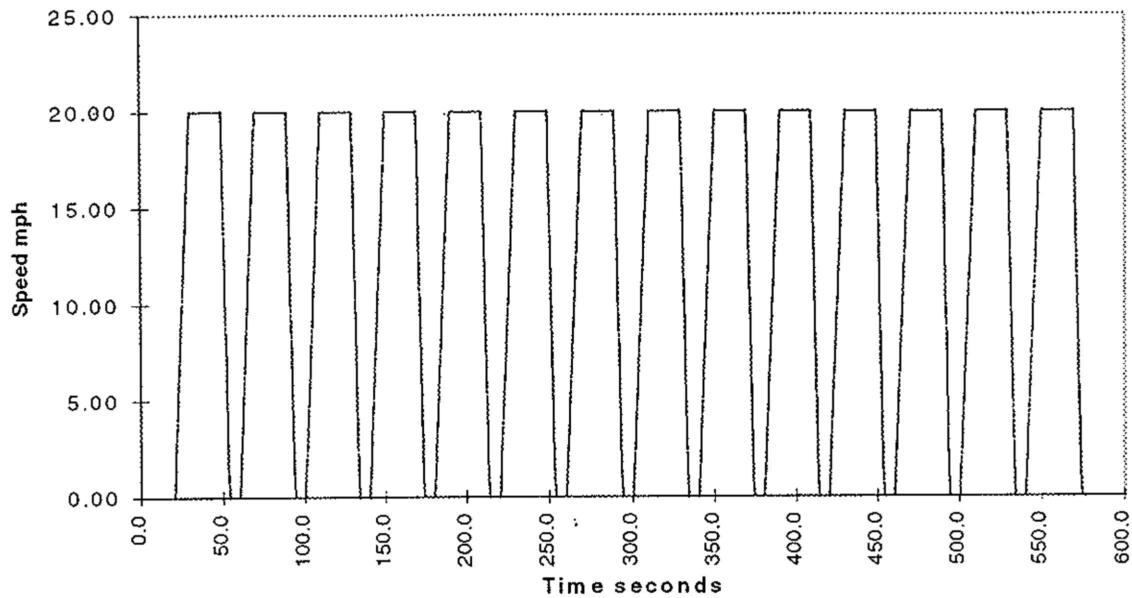

Figure 2. Central Business District Cycle

The bus was also driven over a simulated NYC (New York City) route at different ambient temperatures (24°C, 0°C, and –15°C). This duty cycle was developed by Cummins Inc. and was a simulation of NYC route M103. A speed versus time display of this trace is presented in Figure 3. Engine and exhaust temperatures were measured and logged to determine the effect of the control strategy in varying ambient temperatures. Emissions were not measured over this cycle. The bus was driven for approximately 30 minutes each cycle with the control strategy forced on and off at each of the different temperatures.

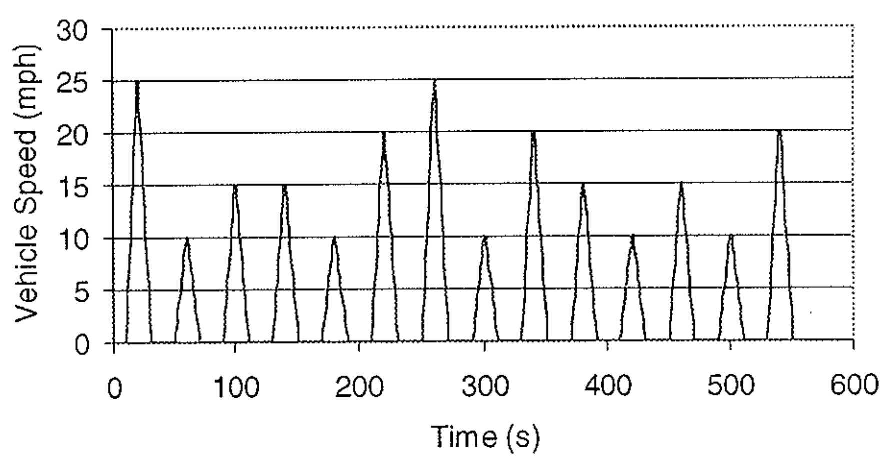

Figure 3. Simulated New York City Driving Cycle –Cummins Inc.

Test Procedure

The test procedures followed for the exhaust emission testing of the heavy duty vehicle are outlined in the US-EPA report entitled "Recommended Practice for Determining Exhaust Emissions from Heavy-Duty Vehicles Under Transient Conditions". The calculations of exhaust emissions and fuel economy were performed in accordance with the US-EPA Code of Federal Regulation, Schedule 40, Part 86.

During each of the test days the vehicle was brought to operating temperature by driving the vehicle at various steady state speeds and simulated CBD accelerations. Following the warm-up the emission tests were conducted as hot starts. Driver variability was eliminated from the results by using the same driver technician for all of the vehicle testing. In general three repeats of each driving cycle were conducted in series, with a 3 minute "soak" or idle period between each repetition.

The particulate traps were "de-greened" for 8 to 10 hours prior to the emissions test program. The traps were installed on the bus by BAE SYSTEMS Controls technical representatives. As stated in the previous paragraph a warm up period occurred prior to initiating the test sequence. Fuel changes were performed in manner that excluded any possibility for fuel contamination.

3.0 MASS EMISSION RATE CALCULATIONS

- *Gaseous Exhaust Emissions*

The final reported exhaust emission test results were calculated using the following formula (CFR Title 40 Part 86.144.90, 86.144.94, 86.145.82):

The mass of each pollutant for each test was determined from the following equations:

Hydrocarbon mass:

$HC\ mass = Vmix * Density\ HC * (Sample\ HC\ (ppm) - (Ambient\ HC\ (ppm)*(1-1/DF)))/10^6$

Oxides of nitrogen mass:

$NO_X\ mass = Vmix * Density\ NO_2$[3] $* KH *(Sample\ NO_X\ (ppm) - (Ambient\ NO_X\ (ppm)*(1-1/DF)))/10^6$

Carbon monoxide mass:

$CO\ mass = Vmix * Density\ CO * (Sample\ CO\ (ppm) - (Ambient\ CO\ (ppm)*(1-1/DF)))/10^6$

Carbon dioxide mass:

$CO_2\ mass = Vmix * Density\ CO_2 * (Sample\ CO_2\ (ppm) - (Ambient\ CO_2\ (ppm)*(1-1/DF)))/10^2$

[3] NO_X is the sum of NO plus NO_2 contained in a gas sample as if the NO_X were in the form of NO_2. (CFR 86.082.2) (3).

Nitric Oxide mass:

*NO mass = Vmix * Density NO * KH * (Sample NO (ppm)- (Ambient NO (ppm)*(1-1/DF)))/10^6*

Nitrogen Dioxide mass:

*NO_2 = Vmix * Density NO_2 * KH * (Sample NO_X - NO (ppm)- (Ambient NO_X (ppm)*(1-1/DF)))/10^6*

Where:

Vmix = total dilute exhaust volume in ft^3 per test corrected to standard conditions.
KH = humidity correction factor used for NO_X emissions.
DF = dilution factor

Densities at 20°C and 101.3 kpa:

CO = 32.97 g/ft^3
CO_2 = 51.81 g/ft^3
THC = 16.33 g/ft^3
NO_2 = 54.16 g/ft^3
NO = 35.35 g/ft^3

The mass of the emission component was divided by the distance traveled over the test cycle resulting in a mass emission rate provided in grams per mile.

- ***Particulate Exhaust Emissions***

The final particulate exhaust emission test results were computed by use of the following formulas:

$$PM = \frac{Vmix * (Pe - Pb)/Vep}{D}$$

Where:

PM = particulate matter in grams/mile
Vmix = total dilute exhaust volume in ft^3 per test corrected to standard conditions
Pe = mass of the particulate per test on the exhaust filter in grams
Pb = mass of the particulate on the " background/tunnel blank" filter in grams
Vep = total dilute exhaust volume in ft^3 per test corrected to standard conditions directed to the exhaust filters
D = distance in miles

- ***Fuel Economy Calculation***

The calculated fuel economy was based on the following carbon balance equation:

$MPG_C = GCPG / (0.866*HC) + (0.429*CO) + (0.273 * CO_2)$

MPG_C = miles per gallon Carbon

GCPG = grams of carbon per gallon fuel

HC, CO, CO_2 in grams per mile

GCPG = 3785.4 * fuel fraction carbon *fuel density

4.0 RESULTS

Table 3 provides the mass emission rates and calculated fuel economy of the Orion VII Hybrid Bus. The emission rates presented for the CBD cycle were not corrected for SOC with the exception of the NEX 0311-5 and –50 which are intended for Orion Bus production. With the hybrid electric vehicle the engine reacts not only to the vehicle loads but also to the battery state of charge and the engine is not necessarily load following. The emissions results for each CBD under different configurations were reported individually, not as an average per configuration. This was done due to the absence of SOC corrections and the lack of consistency within the emission results from test to test.

Technical representatives from BAE SYSTEMS Controls and Cummins Inc. were measuring and logging battery charge and engine parameters during the emissions testing. SOC corrected information and data provided by BAE SYSTEMS Controls is included in Table 4. The averages SOC corrected results for the NEX 0311-5 with LSD and NEX 0311–50 with ULSD are reported in Table 3 as the SOC correction and the sample size provide a more uniform sample set.

The emissions results for the three sets of CBDs are varied, depending on energy gained or lost by the batteries and the generator energy used during the CBD cycle. This is most evident by the varying CO_2 emissions. For the last two devices tested, NEX 0311-5 and NEX 0311-50, six sets of CBDs were run in order to provide a larger data set and to minimize the effects of the varying SOC.

Table 3. Orion VII Hybrid Bus Mass Emission Rates (g/mile) and Calculated Fuel Economy (mpUSg)

Device	Fuel	CBD #	CO g/mile	CO2 g/mile	NOx g/mile	NO2 g/mile	%NO2/NOx	THC g/mile	F.C. mpUSg	PM g/mile
Straight Pipe	ULSD	1	2.2	1397	11.4	1.2	11	0.38	7.1	0.147
	ULSD	2	2.3	2027	15.0	1.3	9	0.47	4.9	0.268
	ULSD	3	2.4	1819	13.7	0.9	7	0.46	5.5	0.239
JMI CRT(improved)	ULSD	1	0.017	2215	14.2	9.4	66	0.16	4.5	0.062
	ULSD	2	0.021	2049	13.2	9.2	70	0.12	4.9	0.031
	ULSD	3	n/c	1592	10.9	8.6	79	0.08	6.3	0.015
MEX 003-50 (internal cone)	ULSD	1	n/c	1600	11.8	3.9	33	0.06	6.2	0.031
	ULSD	2	0.017	2086	13.8	4.5	33	0.08	4.8	bdl
	ULSD	3	0.026	1640	13.6	3.6	26	0.06	6.1	bdl
MEX 003-2	LSD	1	n/c	2216	13.4	0.9	7	0.10	4.4	0.039
	LSD	2	0.37	1397	9.8	0.6	6	0.08	6.9	bdl
	LSD	3	0.37	2067	13.2	0.7	6	0.08	4.7	0.061
MEX 003-50 (internal cone) LSB ON / AC ON	ULSD	1	0.01	2058	15.6	6.5	42	0.06	4.8	0.039
	ULSD	2	0.03	2485	17.9	6.7	37	0.13	4.0	0.015
	ULSD	3	0.02	2153	15.5	5.5	35	0.11	4.6	0.015
MEX 003-50 (internal cone) LSB OFF / AC OFF	ULSD	4	0.03	1397	11.4	1.2	11	0.38	7.1	0.031
	ULSD	5	0.04	2027	15.0	1.3	9	0.47	4.9	0.038
	ULSD	6 10	bdl	1731	13.3	2.5	19	0.30	5.7	0.038
MEX 003-50 (internal cone) LSB ON / AC OFF	ULSD	7	0.03	1818	14.3	4.6	32	0.11	5.5	0.023
	ULSD	8	0.02	1689	13.3	4.9	37	0.10	5.9	0.031
	ULSD	9	0.03	2197	15.9	5.2	33	0.11	4.5	0.023
Straight Pipe	ULSD	1	2.0	1291	11.5	1.3	12	0.52	7.7	0.140
	ULSD	2	2.1	1848	14.6	1.3	9	0.55	5.4	0.220
	ULSD	3	1.9	1541	13.3	1.6	12	0.58	6.4	0.184
NEX 0311-5	ULSD	1	0.11	1403	11.2	1.2	10	0.24	7.1	n/a
	ULSD	2	0.08	2130	14.9	2.6	18	0.14	4.7	0.008
	ULSD	3	0.05	1743	13.4	1.9	14	0.14	5.7	bdl
NEX 0311-5 *	LSD	1	0.11	1459	11.0	1.5	14	0.12	6.6	bdl
	LSD	2	0.05	2204	14.4	2.5	17	0.13	4.4	0.015
	LSD	3	0.1	1602	12.4	1.5	12	0.14	6.0	bdl
	LSD	4	n/c	1649	12.4	1.7	14	0.17	5.9	0.023
	LSD	5	n/c	2144	14.8	2.2	15	0.14	4.5	0.023
	LSD	6	n/c	1517	11.6	1.3	12	0.12	6.4	0.015
Average SOC Corrected	**LSD**			**1820**	**13.3**				**5.3**	**0.013**
NEX 0311-50*	ULSD	1	n/c	1718	12.1	5.4	45	0.07	5.8	0.008
	ULSD	2	n/c	1597	12.2	6.3	52	0.07	6.2	bdl
	ULSD	3	n/c	2088	14.3	6.8	47	0.07	4.8	0.015
	ULSD	4	0.19	1723	12.2	3.8	31	0.19	5.8	0.031
	ULSD	5	0.03	1663	12.1	3.8	31	0.21	6.0	0.016
	ULSD	6	0.02	2422	15.0	7.1	47	0.07	4.1	bdl
Average SOC Corrected	**ULSD**			**1848**	**12.9**				**5.4**	**0.012**
NEX 0311-50	LSD	1	n/c	1702	12.0	5.7	47	0.09	5.7	0.039
	LSD	2	0.02	2251	14.1	5.7	41	0.11	4.3	0.251
	LSD	3	0.01	1768	12.6	4.6	37	0.09	5.5	0.070

n/c = not collected
bdl = below reportable instrument detection limits
Approximate detection limit for PM ~0.008g/mile
All values not corrected for state of charge except where stated
** intended for use in production by Orion Bus*

Table 4. Orion VII Hybrid Bus Emission Results for Selected Tests - SOC Correction

Device	Fuel	CBD #	CO2 g/mile	NOx g/mile	F.C. mpUSg	PM g/mile	SOC Corrected Values NOx g/mile	SOC Corrected Values PM g/mile	SOC Corrected Values CO2 g/mile	SOC Corrected Values F.C. mpUSg
NEX 0311-5*	LSD	1	1459	11.0	6.6	bdl	14.004	bdl	1864	5.20
	LSD	2	2204	14.4	4.4	0.0154	12.630	0.0135	1932	5.01
	LSD	3	1602	12.4	6.0	bdl	13.193	bdl	1708	5.67
	LSD	4	1649	12.4	5.9	0.0231	13.552	0.0252	1795	5.39
	LSD	5	2144	14.8	4.5	0.0230	12.374	0.0193	1798	5.39
	LSD	6	1517	11.6	6.4	0.0155	13.871	0.0185	1820	5.32
Average Values			1763	12.753	5.64	0.0128	13.271	0.0128	1820	5.33
NEX 0311-50*	ULSD	1	1718	12.1	5.8	0.0078	12.624	0.0081	1794	5.54
	ULSD	2	1597	12.2	6.2	bdl	14.046	bdl	1834	5.42
	ULSD	3	2088	14.3	4.8	0.0154	12.044	0.0130	1760	5.65
	ULSD	4	1723	12.2	5.8	0.0312	13.110	0.0337	1858	5.35
	ULSD	5	1663	12.1	6.0	0.0156	14.035	0.0181	1928	5.16
	ULSD	6	2422	15.0	4.1	bdl	11.813	bdl	1911	5.21
Average Values			1868	12.972	5.44	0.0117	12.945	0.0122	1848	5.39

n/c = not collected
bdl = below reportable instrument detection limits
Approximate detection limit for PM ~0.008g/mile
** intended for use in production by Orion Bus*

5.0 DISCUSSION

The purpose of the emissions test program was to determine the effect that the hybrid propulsion system, particulate traps and fuel configurations have on exhaust emissions. The main objective of the testing was to achieve exhaust emission rates of 15.0 g/mile NO_x and 0.06 g/mile PM.

Device and Fuel Configurations

In comparison to the baseline test configuration, straight exhaust pipe, all of the devices tested showed significant emissions reductions of CO by ~ 97 %, THC by ~ 70%, and PM by ~ 82%. These percentages were calculated based on an average of all of the device emission test results. Differences in fuel economy with the straight pipe and the particulate traps were not evident.

Two devices, NEX 0311-5 and NEX 0311-50 were tested with both LSD and ULSD. The increased sulphur fuel had limited effects on the emission results with the exception of the increased PM with the LSD. It should be noted that hydrocarbon speciation was not performed during the emissions testing.

NO_x Emissions

Typically, the majority of diesel NO_x exhaust is composed of NO as is demonstrated with the baseline tests, i.e. ~ 90% NO assuming NO_x = NO plus NO_2. The JMI CRT showed the most production of NO_2 at ~ 71%. This was expected as the JMI CRT technology uses NO_2 to remove PM from the exhaust. However, the overall NO_x production was not increased compared to the NO_x emissions from the other devices. The MEX 003-2 showed the most NO production compared with the traps and the baseline configuration.

The limit of 15.0 g/mile NO_x was met for all tests with the exception of one of the tests with the NEX 0311-50 trap which was 15.9 g/mile. One test each with the straight pipe, the MEX 0003-50 filter and the NEX 0311-50 were at 15.0 g/mile. As expected, the results with the MEX 0003-50 filter and the A/C ON showed increased NO_x and CO_2 results.

PM Emissions

Diesel particulate matter is a complex mix of particles having different chemical compositions. Controversy exists in several areas relating to the collection of samples of particulate matter from mobile sources in a laboratory setting. The process of diluting the hot exhaust from engines or vehicles can produce sampling artifacts that can bias chemical analysis results. Careful attention must be paid to both the dilution process and the collection of samples in order to collect valid samples and make valid measurements.

With the Orion VII Hybrid bus there was relatively low filter mass loading over the CBD cycle. The visual appearance of the Pallflex filters did not indicate any loading and several of the PM mass emission rates were below the detection limits reportable based on the relatively small weight gain on the Pallflex filters.

However, it can be stated that all of the PM values measured, with the exception of those with the straight pipe and one of the tests with the JMI CRT and two tests with the NEX 0311-50 with LSD, the objective of 0.06 g/mile PM was met. The PM values; 0.62 g/mile with JMI CRT and 0.251 g/mile look suspect with respect to all of the other measured PM and are assumed to be sampling artifacts. With these values excluded it would appear that these traps are capable of producing emission rates below 0.06 g/mile PM.

Teflon membrane filters were used to collect particle phase sulphate from the exhaust stream. Ion chromatography is the analysis method used for the sulphate determination. To date, the results of this analysis are not completed and these results will be added to this report as an addendum. The reporting of the sulphate mass emission rates may be limited due to the relatively low filter mass loading.

Other detailed analysis of the PM was not performed i.e., organic carbon, elemental carbon, particle sizing, etc. and therefore the effects of the devices on PM speciation are beyond the scope of this program.

Due to the limited PM mass and the lack of repeatability within test runs it is not warranted to make specific comparisons between the emissions results with the different devices.

In summary, the mass emission rates from the Orion VII Hybrid bus were collected with different particulate traps and fuel configurations. All of the traps tested showed decreased emission results compared to the straight pipe and LSD fuel. The use of the LSD fuel with two traps produced increased PM results compared to the ULSD fuel. In general, the objectives of 15.0 g/mile NO_X and 0.06 g/mile PM were met with all of the traps tested in this program.

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