

Acceleration and Braking Performance of School Buses

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ABSTRACT

There is a limited amount of data currently available on the acceleration and braking performances of school buses. This paper analyzes the braking performance of various Type A and Type C school buses with hydraulic and air brakes. The effect of ABS and Non-ABS systems as well as driver experience is discussed. A comparison with passenger car braking performance is presented. The acceleration of a school bus is also presented. Evaluations of “normal” and “rapid” accelerations are presented for Type A and Type B buses. A comparison with commonly used acceleration values for various vehicles is presented.

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INTRODUCTION

The acceleration and braking performance of school buses have not been well documented in the literature when compared to the documentation available for passenger vehicles and heavy trucks [1,2,3,4,5,6,7,8,9]. Gattis, et al. [10] conducted speed, time, and distance measurements for full-size school buses to assess intersection sight distances with data collected at travel distances of 18 m through 500 m. No brake testing was conducted in the Gattis, et al. [10] study and acceleration data was only collected at specified locations versus continuous data acquisition. Zagorski, et al. [9] conducted brake testing on commercial vehicles equipped with air-disc brakes at high travel speeds. A large school bus (77 passenger capacity) was used as one of the test vehicles and was evaluated in both lightly loaded and Gross Vehicle Weight Rating (GVWR) loaded conditions. Standard S-cam and hybrid disc brake configurations were used and the average deceleration for the school bus ranged between 0.439 g and 0.697 g depending on the loading conditions and brake system configuration [9]. No acceleration data for school buses was collected in the Zagorski, et al [9] study.

There are four types of school buses [11]:

- Type A: Bus body constructed on a cutaway front section vehicle with a left side driver's door entrance, passenger entrance door behind the front wheels.
- Type B: Body installed on a stripped chassis and the entrance door is behind the front wheels.
- Type C: Body installed on a chassis with a hood and front fender assembly. The entrance door is behind the front wheels and is often referred to as a conventional style school bus.
- Type D: Body installed on a stripped chassis. The entrance door is forward of the front wheels and the bus has a flat front styling.

The aforementioned studies were conducted using large school buses of Type C and Type D body style construction. The combination of acceleration and braking testing was not presented in these studies. This work focuses on analyzing the acceleration and braking characteristics of Type A and Type C school buses, whose body styles are commonly used by school districts. Often, an accident reconstructionist

Table 1. School bus parameters

Parameter	Bus 1	Bus 2	Bus 3	Bus 4
Model Year	2011	1996	2006	2011
Capacity	24 + driver	65 + driver	65 + driver	75+driver
Brake System	Hydraulic, Disc, ABS	Hydraulic, Disc, No ABS	Hydraulic, Disc, ABS	Air, Drum, ABS
GVWR (lb/kg)	12,300 lb / 5,579 kg	27,500 lb / 12,474 kg	29,760 lb / 13,499 kg	31,000 lb / 14,061 kg
Curb Weight (lb/kg)	9,305 lb / 4,221 kg	17,620 lb / 7,992 kg	18,330 lb / 8,314 kg	20,785 lb / 9,428 kg
Weight Distribution	45% front, 55% rear	42% front, 58% rear	44% front, 56% rear	37% front, 63% rear
Overall length (in/m)	245 inches / 6.22 m	421 inches / 10.69 m	421 inches / 10.69 m	475 inches / 12.07 m
Wheelbase (in/m)	149 inches / 3.78 m	254 inches / 6.45 m	254 inches / 6.45 m	276 inches / 7.01 m
Front Tires	LT225/75R16	10R22.5	10R22.5	11R22.5
Rear Tires	LT225/75R16	10R22.5	10R22.5	11R22.5

employs an average acceleration for a vehicle accelerating from a stop. The effect of the acceleration as a function of distance is presented for automatic and manual transmissions. The acceleration and braking profiles for each run, as well as their influence from different drivers, is presented. A comparison of ABS and non-ABS hydraulic brakes, and ABS air braked buses is presented.

METHODOLOGY

Four school buses were used in the subject testing. Bus 1 was a Type A body construction with an automatic transmission, ABS, and hydraulic brakes. Bus 2 was a Type C body construction with a manual transmission, no ABS, and hydraulic brakes. Bus 3 was a Type C body construction with an automatic transmission, ABS, and hydraulic brakes. Bus 4 was a C type body construction with an automatic transmission, ABS, and air brakes. Other parameters for the four buses are shown in [Table 1](#).

The school buses were weighed using CAD Road Weigher scales (Model RW-05S) and each scale had a 10,000 lb (4,536 kg) capacity and accuracy of 5 lb (2.3 kg). The weights listed in [Table 1](#) were obtained with the driver seated in the driver's seat and one passenger located directly behind the driver with a combined weight of approximately 385 lb (175 kg). Each school bus was instrumented with a Vericom 4000DAQ with an external pressure sensor trigger affixed on the accelerator during the accelerator tests or on the brake pedal during the braking tests. The application of the pressure sensor triggered the initiation of the Vericom software and the start of each run. The Vericom 4000DAQ is equipped with a tri-axial accelerometer, a crystal clock, a microcontroller, and angular rate gyros (30 degrees per second) for measuring yaw and adjusting automatically for changes in vehicle pitch during testing [12]. Based on the acceleration (100 Hz) and time measurements, the velocity

and distance at each time step (0.01 seconds) is calculated by the integral software. A 10 Hz GPS is built in to the Vericom 4000DAQ to provide a comparison with the velocity calculated from the acceleration data. The test configuration for the testing is shown in [Figure 1](#).

The testing was conducted on a two-lane roadway composed of bituminous asphalt and testing was conducted within the same area for all runs. The acceleration and braking runs were conducted by certified school bus drivers. One driver conducted the acceleration and braking runs for all four school buses. This driver was experienced in school bus acceleration and braking testing and is referred to as Driver 1. In addition to the experienced test driver, two active school bus drivers, labeled Driver 2 and Driver 3 conducted testing on Bus 3, which was a bus configuration used on their daily routes. Driver 2 had 13 years of school bus driving experience and Driver 3 had 5 years of experience. A fourth driver, Driver 4, conducted acceleration and braking runs on Bus 4. Driver 4 had previous experience with passenger vehicle acceleration and braking testing, but had not previously conducted testing with school buses.

The Vericom 4000DAQ software allows the user to select how the acceleration runs are conducted using either distance or speed as the two metrics. A distance of 150 feet (45.7 m) was selected as the distance for all of the acceleration runs. As mentioned, an external pressure sensor was placed on the accelerator pedal during the acceleration runs that initiated the run. The termination of the run was achieved at the predetermined 150 feet independent of driver inputs. At the beginning and end of the run, the computer produced an audible noise indicating the onset and termination of the event, respectively. The drivers were instructed to accelerate "normally" and "rapidly" in order to compare the difference between these acceleration rates as well as compare the rates to the other drivers. Three runs for "normal" and three runs

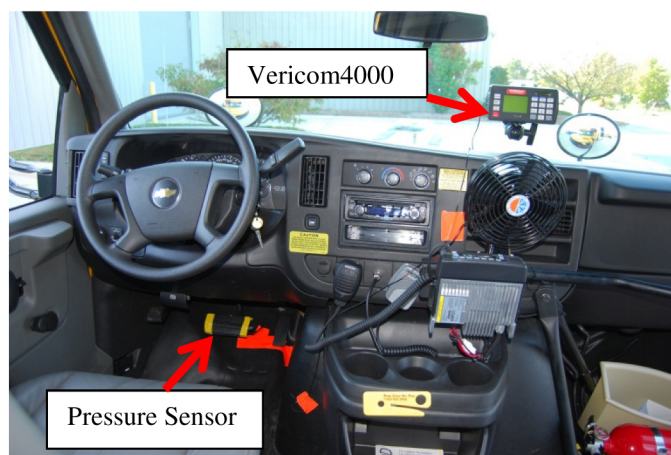


Figure 1. Test Setup

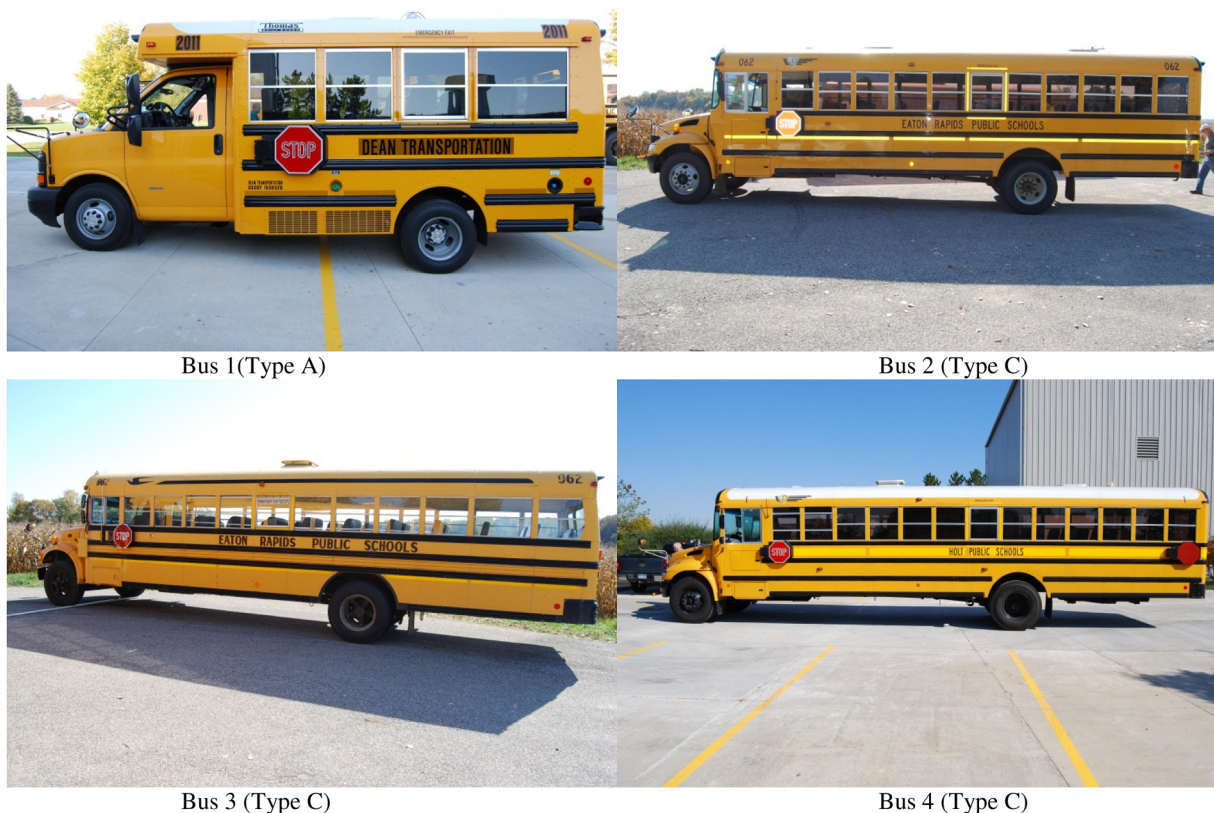


Figure 2. School buses used in testing

for “rapid” were obtained for each driver on a specific bus. The drivers were told to continuously apply the accelerator from the onset of accelerator pressure until the run was complete.

For the braking runs, the pressure sensor was placed on the brake pedal. The drivers were instructed to accelerate to approximately 40 mph (64.4 kph) and then apply the brakes with maximum effort and continuous pressure until the vehicle stopped. There was no acceleration level threshold

required to start the braking runs. The application of the brake pedal pressure sensor triggered the computer to start recording the acceleration data during the braking run and the event was terminated automatically by the Vericom software when the vehicle stopped. The acceleration and braking runs were conducted primarily with a driver and two to four passengers. No tests were conducted at the GVWR of the buses. The four buses used in the subject testing are shown in [Figure 2](#).

RESULTS

ACCELERATION

Bus 1 Acceleration Characteristics

The raw data plots from the acceleration runs for Bus 1, the Type A school bus with an automatic transmission, ABS, and hydraulic brakes, are shown in [Figure 3](#) (normal acceleration) and [Figure 4](#) (rapid acceleration). Driver 1 conducted all of the acceleration runs for Bus 1. The acceleration traces for the normal accelerations in [Figure 3](#) and rapid accelerations in [Figure 4](#) show several distinct traits. At the onset of each acceleration run, the school bus had a higher acceleration rate during the first second of travel. The acceleration decreased during the remainder of the acceleration run as the school bus continued to increase its speed and the transmission shifted into higher gear positions. The velocity curves indicated that the acceleration was not constant during the normal and rapid runs over the 150 feet (45.7 m) distance. Three distinct slope differences were noted in the velocity traces for both the normal and rapid acceleration runs.

The acceleration runs were then segmented into various distances to observe any variations in the acceleration level and to observe if any changes in acceleration during each run affected the normally assumed linear velocity profile from a constant vehicle acceleration assumption. The results are shown in [Table 2](#) and [Table 3](#). The results showed that the average acceleration during the first 20 feet of travel was higher than the average acceleration over the entire 150 feet travel test distance. The general trend for both the normal and rapid accelerations were that the average acceleration decreased as the distance traveled increased. The averages of the "Normal" and "Rapid" acceleration runs over a distance of 150 ft (45.7 m) were 0.112 g and 0.257 g, respectively. [Table 2](#) and [Table 3](#) also showed that in the first 20 ft (6.1 m) of travel, the normal and rapid accelerations for the Type A bus were similar to published data for normal and rapid acceleration values for passenger vehicles [1] at 0.162 g and 0.332 g, respectively. As noted, the velocity shown in [Table 2](#) and [Table 3](#) was calculated directly by the Vericom software based on the instantaneous acceleration and time. The data from the GPS velocity recorded at 10 Hz is not shown, but the difference in the velocity data between the GPS and Vericom calculation was less than 2 mph. The equation for a vehicle accelerating from a stop is shown in [Eq. 1](#) as:

$$V = \sqrt{2ax}$$

Eq 1

where a is the acceleration, x is the distance and V is the velocity. Over a known distance, a constant acceleration is assumed to calculate the velocity. [Table 2](#) and [Table 3](#) showed the the calculation of the velocity from [Eq. 1](#) in comparison to the value calculated by Vericom. The results showed that [Eq. 1](#) calculated the vehicle velocity within 3.8%

to 10.6% (0.36 mph to 2.14 mph) of the Vericom results for the normal acceleration runs and -2.2% to 7.6% (-0.32 mph to 2.46 mph) of the Vericom for the rapid runs. The negative sign in the rapid runs indicated that the calculated vehicle in speed [Eq. 1](#) was less than the Vericom. In general, [Eq. 1](#) showed reasonable agreement with the Vericom velocity results and the effect of slope variations for the velocity had minimal impact on the calculation.

Table 2. Acceleration versus Distance Analysis for Bus 1 with Normal Acceleration

Normal	Acceleration	Velocity	Velocity	Velocity (Eq 1)	Velocity (Eq 1)	Difference
Run 1	g	mph	kph	mph	kph	%
0-20 ft (6.1 m)	0.139	8.4	13.5	9.1	14.7	8.7%
0-50 ft (15.2 m)	0.125	12.8	20.7	13.7	22.0	6.7%
0-100 ft (30.5 m)	0.108	16.6	26.7	18.0	29.0	8.4%
0-150 ft (45.7 m)	0.100	19.4	31.2	21.2	34.1	9.0%
Normal	Acceleration	Velocity	Velocity	Velocity (Eq 1)	Velocity (Eq 1)	Difference
Run 2	g	mph	kph	mph	kph	%
0-20 ft (6.1 m)	0.166	9.6	15.5	10.0	16.0	3.8%
0-50 ft (15.2 m)	0.148	14.2	22.8	14.9	24.0	5.0%
0-100 ft (30.5 m)	0.130	18.4	29.6	19.7	31.8	7.2%
0-150 ft (45.7 m)	0.120	21.5	34.6	23.2	37.4	8.1%
Normal	Acceleration	Velocity	Velocity	Velocity (Eq 1)	Velocity (Eq 1)	Difference
Run 3	g	mph	kph	mph	kph	%
0-20 ft (6.1 m)	0.182	9.6	15.4	10.4	16.8	9.3%
0-50 ft (15.2 m)	0.149	13.6	21.8	15.0	24.1	10.2%
0-100 ft (30.5 m)	0.127	17.6	28.4	19.5	31.4	10.6%
0-150 ft (45.7 m)	0.117	20.8	33.4	22.9	36.9	10.3%

Table 3. Acceleration versus Distance Analysis for Bus 1 with Rapid Acceleration

Rapid	Acceleration	Velocity	Velocity	Velocity (Eq 1)	Velocity (Eq 1)	Difference
Run 1	g	mph	kph	mph	kph	%
0-20 ft (6.1 m)	0.360	14.4	23.2	14.7	23.6	2.1%
0-50 ft (15.2 m)	0.333	21.6	34.8	22.3	35.9	3.2%
0-100 ft (30.5 m)	0.292	27.8	44.8	29.6	47.6	6.3%
0-150 ft (45.7 m)	0.270	32.4	52.1	34.8	56.1	7.6%
Rapid	Acceleration	Velocity	Velocity	Velocity (Eq 1)	Velocity (Eq 1)	Difference
Run 2	g	mph	kph	mph	kph	%
0-20 ft (6.1 m)	0.281	12.7	20.4	13.0	20.9	2.2%
0-50 ft (15.2 m)	0.251	18.5	29.8	19.4	31.2	4.7%
0-100 ft (30.5 m)	0.229	24.8	40.0	26.2	42.2	5.5%
0-150 ft (45.7 m)	0.218	29.6	47.7	31.3	50.4	5.8%
Rapid	Acceleration	Velocity	Velocity	Velocity (Eq 1)	Velocity (Eq 1)	Difference
Run 3	g	mph	kph	mph	kph	%
0-20 ft (6.1 m)	0.352	14.8	23.7	14.5	23.4	-1.6%
0-50 ft (15.2 m)	0.319	21.4	34.4	21.9	35.2	2.3%
0-100 ft (30.5 m)	0.290	28.1	45.3	29.5	47.4	4.8%
0-150 ft (45.7 m)	0.273	33.1	53.2	35.0	56.3	5.9%
Rapid	Acceleration	Velocity	Velocity	Velocity (Eq 1)	Velocity (Eq 1)	Difference
Run 4	g	mph	kph	mph	kph	%
0-20 ft (6.1 m)	0.335	14.5	23.3	14.2	22.8	-2.2%
0-50 ft (15.2 m)	0.313	21.4	34.5	21.6	34.8	1.1%
0-100 ft (30.5 m)	0.285	28.0	45.1	29.2	47.0	4.1%
0-150 ft (45.7 m)	0.267	32.8	52.8	34.6	55.7	5.6%

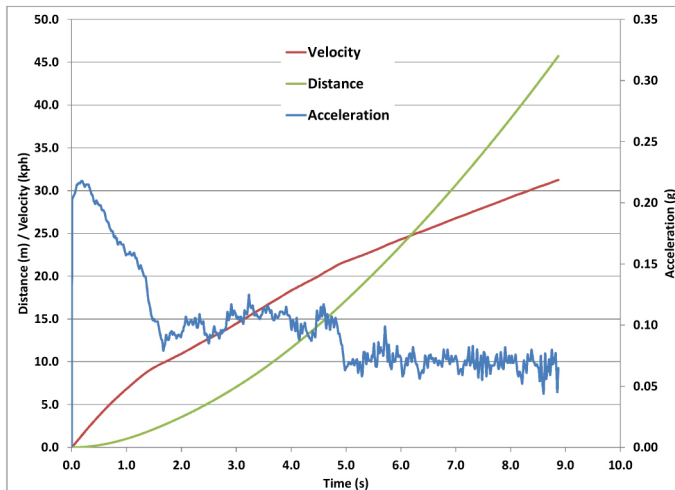
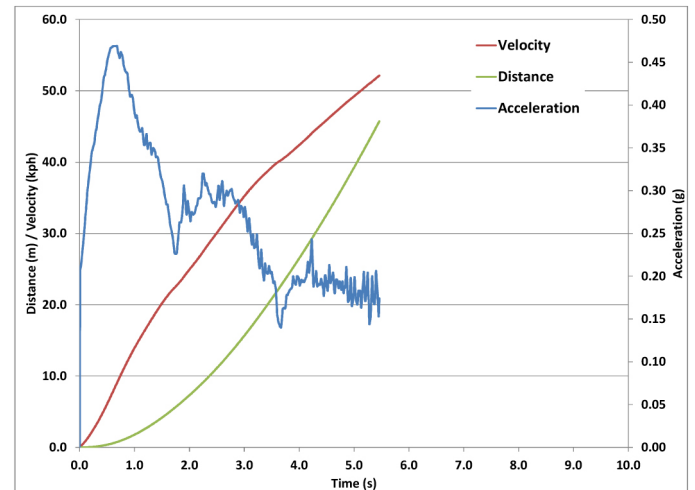
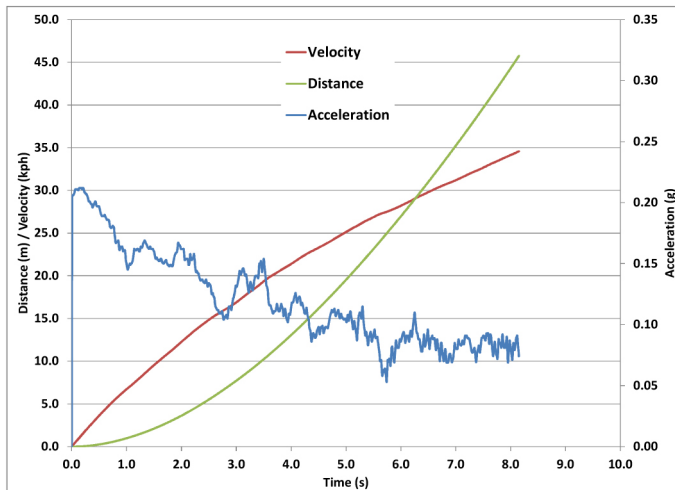
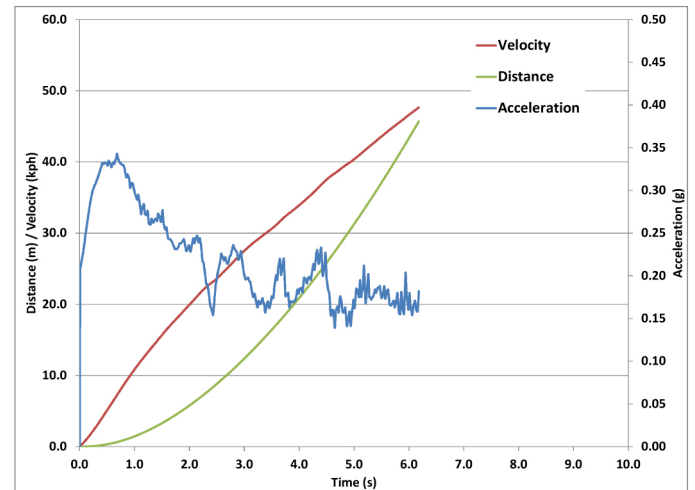
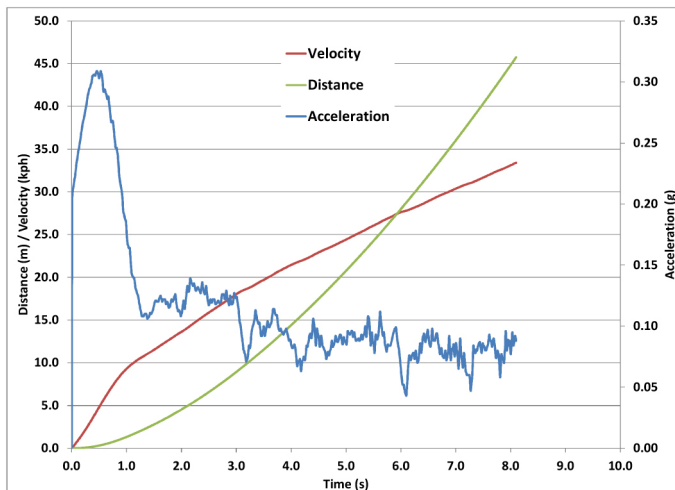
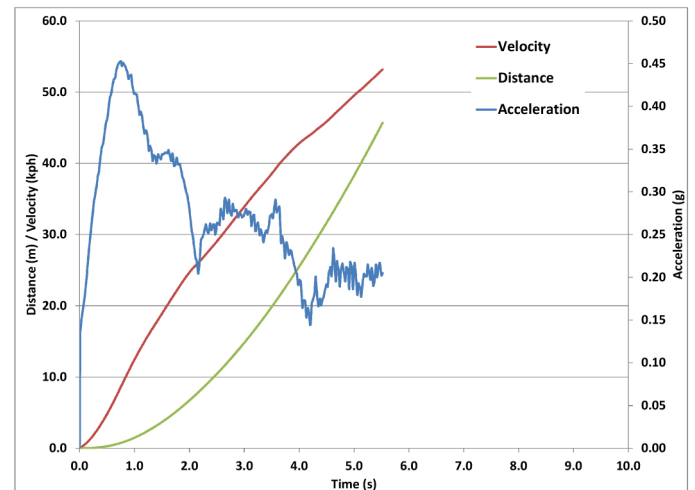
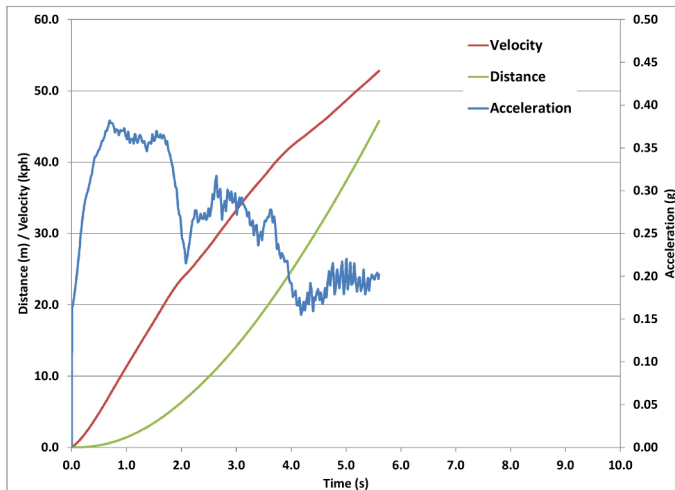
**Run 1****Run 1****Run 2****Run 2****Run 3****Run 3**

Figure 3. Normal Acceleration Runs for Type A School Bus, Bus 1 with Driver 1

Figure 4. Rapid Acceleration Runs for Type A School Bus, Bus 1 with Driver 1



Run 4

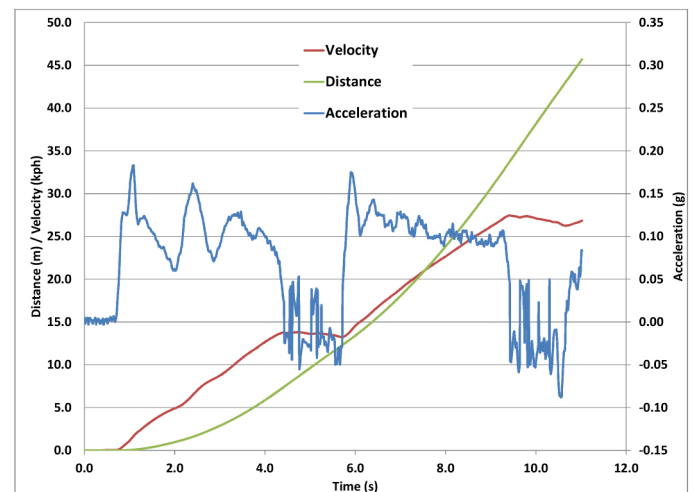
Figure 4 (cont.). Rapid Acceleration Runs for Type A School Bus, Bus 1 with Driver 1

Bus 2 Acceleration Characteristics

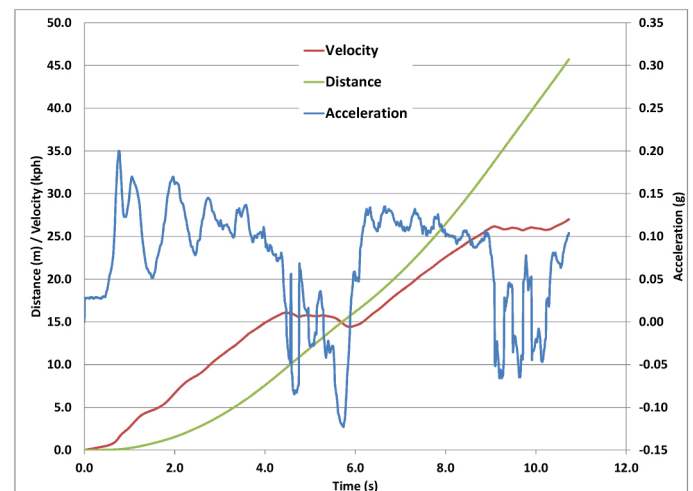
The raw data plots from the acceleration runs for Bus 2, the Type C school bus with a manual transmission, no ABS, and hydraulic brakes, are shown in [Figure 5](#) (normal acceleration) and [Figure 6](#) (rapid acceleration). Driver 1 conducted all of the acceleration runs for Bus 2. The acceleration traces for the normal accelerations in [Figure 5](#) and rapid accelerations in [Figure 6](#) show several distinct traits. In general, the overall acceleration profiles for Bus 2 were different than Bus 1. No distinct rapid acceleration was observed at the onset of each run as was present with Bus 1. Several acceleration peaks were observed during the normal and rapid runs primarily at the transmission shift points. The transmission shift points resulted in oscillatory patterns in the acceleration data. The transmission shifts also caused periods of nearly constant velocity as well as negative accelerations as the driver shifted and the vehicle transitioned to its higher gear position. This was mostly evident in the normal acceleration runs. In the rapid acceleration runs, each run concluded during a gear shift as shown in [Figure 6](#). While Driver 1 was experienced at driving a manual transmission school bus, a less experienced driver may cause different shift patterns that could affect the average acceleration value over a defined distance.

Similar to Bus 1, the acceleration runs were segmented into various distances to observe any variations in the acceleration level and are shown in [Table 4](#) and [Table 5](#). Unlike Bus 1, the results did not indicate a trend in the average acceleration over the various test distances. Additionally, there was no significant difference in the acceleration between the normal and rapid runs as with Bus 1. The averages of the “Normal” and “Rapid” acceleration runs over a distance of 150 ft (45.7 m) were 0.072 g and 0.094 g, respectively. [Table 4](#) and [Table 5](#) showed the the

calculation of the velocity from [Eq 1](#) in comparison to the value calculated by Vericom. The results showed that [Eq 1](#) calculated the vehicle velocity within -8.5% to 14.1% (-0.68 mph to 1.4 mph) of the Vericom results for the normal acceleration runs and -2.2% to 7.6% (-0.4 mph to 1.1 mph) of the Vericom results for the rapid runs. The negative sign in the rapid runs indicated that the calculated vehicle in speed [Eq 1](#) was less than the Vericom. In general, [Eq 1](#) showed reasonable agreement with the Vericom velocity results.



Run 1



Run 2

Figure 5. Normal Acceleration Runs for Type C School Bus, Bus 2 with Driver 1

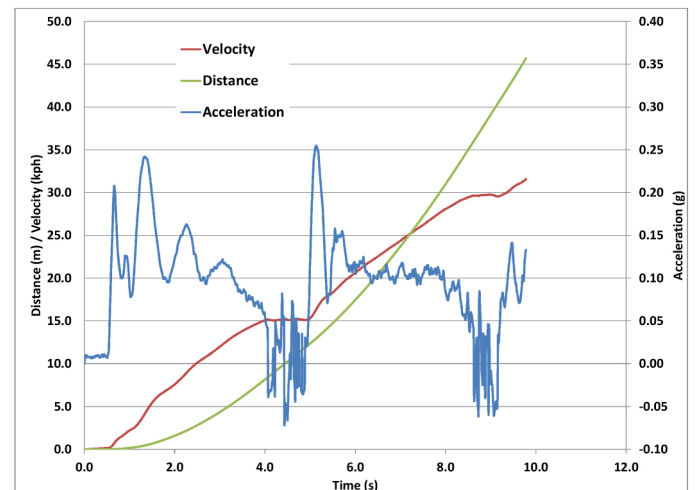
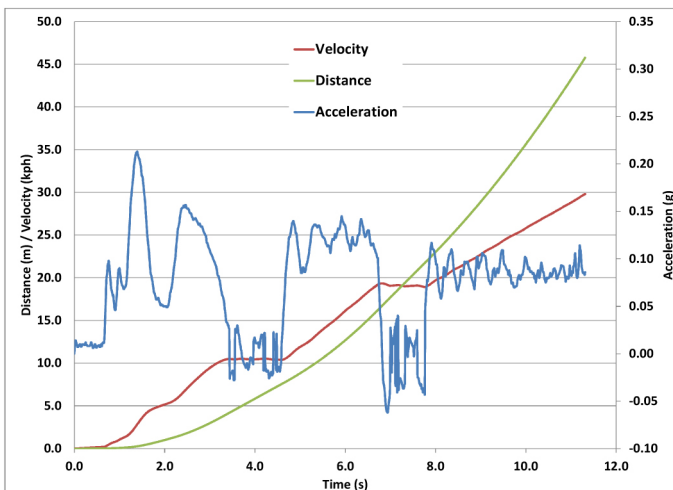
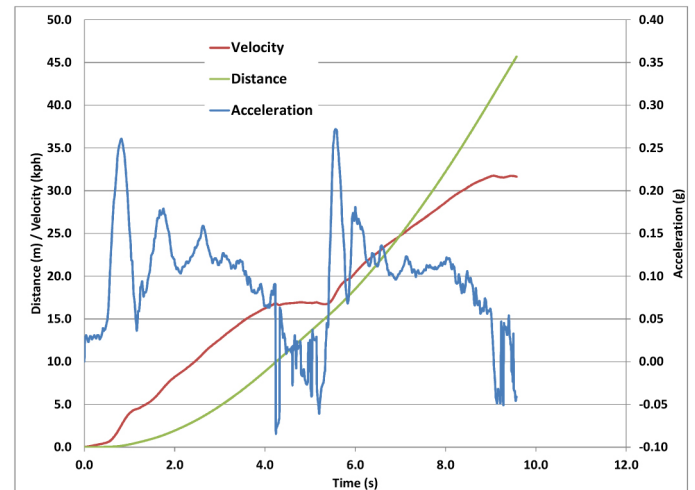
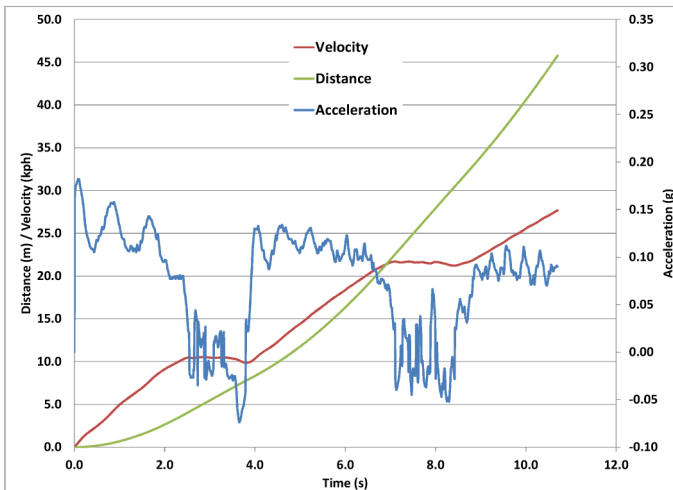


Figure 5 (cont.). Normal Acceleration Runs for Type C School Bus, Bus 2 with Driver 1

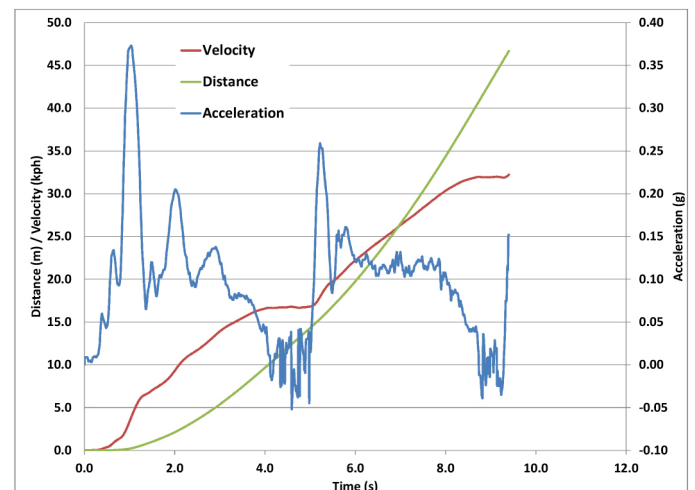


Figure 6. Rapid Acceleration Runs for Type C School Bus, Bus 2 with Driver 1

Table 4. Acceleration versus Distance Analysis for Bus 2 with Normal Acceleration

Normal	Acceleration	Velocity	Velocity	Velocity (Eq 1)	Velocity (Eq 1)	Difference
Run 1	g	mph	kph	mph	kph	%
0-20 ft (6.1 m)	0.090	8.0	12.9	7.3	11.8	-8.5%
0-50 ft (15.2 m)	0.072	10.2	16.4	10.4	16.8	1.9%
0-100 ft (30.5 m)	0.082	16.2	26.1	15.7	25.2	-3.2%
0-150 ft (45.7 m)	0.069	16.7	26.9	17.6	28.3	5.5%
Normal	Acceleration	Velocity	Velocity	Velocity (Eq 1)	Velocity (Eq 1)	Difference
Run 2	g	mph	kph	mph	kph	%
0-20 ft (6.1 m)	0.106	8.4	13.6	8.0	12.8	-5.5%
0-50 ft (15.2 m)	0.072	9.1	14.6	10.4	16.7	14.1%
0-100 ft (30.5 m)	0.081	15.4	24.7	15.6	25.1	1.5%
0-150 ft (45.7 m)	0.071	16.8	27.0	17.9	28.8	6.6%
Normal	Acceleration	Velocity	Velocity	Velocity (Eq 1)	Velocity (Eq 1)	Difference
Run 3	g	mph	kph	mph	kph	%
0-20 ft (6.1 m)	0.092	6.5	10.5	7.4	12.0	14.1%
0-50 ft (15.2 m)	0.086	10.9	17.6	11.4	18.3	3.9%
0-100 ft (30.5 m)	0.071	13.2	21.2	14.6	23.5	10.7%
0-150 ft (45.7 m)	0.073	17.2	27.7	18.1	29.2	5.4%
Normal	Acceleration	Velocity	Velocity	Velocity (Eq 1)	Velocity (Eq 1)	Difference
Run 4	g	mph	kph	mph	kph	%
0-20 ft (6.1 m)	0.073	6.5	10.5	6.6	10.6	1.2%
0-50 ft (15.2 m)	0.080	11.5	18.4	10.9	17.6	-4.5%
0-100 ft (30.5 m)	0.072	14.6	23.5	14.7	23.6	0.4%
0-150 ft (45.7 m)	0.075	18.5	29.8	18.3	29.5	-1.2%

Table 5. Acceleration versus Distance Analysis for Bus 2 with Rapid Acceleration

Rapid	Acceleration	Velocity	Velocity	Velocity (Eq 1)	Velocity (Eq 1)	Difference
Run 1	g	mph	kph	mph	kph	%
0-20 ft (6.1 m)	0.119	8.7	14.1	8.4	13.6	-3.4%
0-50 ft (15.2 m)	0.088	10.4	16.8	11.5	18.5	10.5%
0-100 ft (30.5 m)	0.101	17.3	27.8	17.4	28.0	0.8%
0-150 ft (45.7 m)	0.094	19.7	31.6	20.5	33.0	4.3%
Rapid	Acceleration	Velocity	Velocity	Velocity (Eq 1)	Velocity (Eq 1)	Difference
Run 2	g	mph	kph	mph	kph	%
0-20 ft (6.1 m)	0.112	8.6	13.8	8.2	13.2	-4.5%
0-50 ft (15.2 m)	0.095	11.7	18.8	11.9	19.2	2.1%
0-100 ft (30.5 m)	0.099	17.3	27.8	17.2	27.8	-0.3%
0-150 ft (45.7 m)	0.091	19.6	31.6	20.3	32.6	3.3%
Rapid	Acceleration	Velocity	Velocity	Velocity (Eq 1)	Velocity (Eq 1)	Difference
Run 3	g	mph	kph	mph	kph	%
0-20 ft (6.1 m)	0.130	9.1	14.6	8.8	14.2	-2.6%
0-50 ft (15.2 m)	0.097	11.0	17.7	12.0	19.4	9.4%
0-100 ft (30.5 m)	0.107	17.7	28.4	17.9	28.8	1.3%
0-150 ft (45.7 m)	0.097	19.8	31.9	20.9	33.6	5.4%

Bus 3 Acceleration Characteristics

The raw data plots from the acceleration runs for Bus 3, the Type C school bus with an automatic transmission, ABS, and hydraulic brakes, are shown in [Figure 7](#), [Figure 8](#), [Figure 9](#) (normal acceleration) and [Figure 10](#), [Figure 11](#), [Figure 12](#) (rapid acceleration). Three different drivers were used for Bus 3. Unlike Bus 1 and Bus 2, the acceleration testing for Bus 3 involved two school bus drivers from a local school district. The goal was to observe any differences in “normal” and “rapid” acceleration runs between an experienced test driver and two school bus drivers with no prior testing experience. The school bus drivers were told to accelerate three times at a “normal” rate, which was intended to indicate their daily driving routine. After the three “normal” runs, the drivers were then told to conduct three “rapid” acceleration runs. None of the bus drivers were present inside the school bus during the test runs of the other drivers. The two school

bus drivers were designated Driver 2 (13 years experience) and Driver 3 (5 years experience). Driver 1 (experienced test driver) also conducted the acceleration runs for comparison. The acceleration traces for the normal accelerations in [Figure 5](#) and rapid accelerations in [Figure 10](#), [Figure 11](#), [Figure 12](#) show several distinct traits. Similar to Bus 2, no distinct rapid acceleration was observed at the onset of each normal acceleration run as with Bus 1. An initial rapid acceleration was observed at the onset of the rapid acceleration runs. Additionally, unlike Bus 2, the automatic transmission shift points were not readily detectable and no significant acceleration decrease or constant velocity periods were observed. It is noted that in Run 1 for Driver 2, there was an interruption in the acceleration data approximately 6 seconds into the run and that data was not included.

The acceleration runs were segmented into various distances to observe any variations in the acceleration level and are shown in [Table 6](#) and [Table 7](#). The results showed that there were no notable differences between Driver 1, Driver 2, and Driver 3 in the average and rapid acceleration runs. The averages of the “normal” acceleration runs over a distance of 150 ft (45.7 m) were 0.112, 0.104, and 0.100 g for Driver 1, Driver 2, and Driver 3, respectively. The averages of the normal acceleration runs varied only 10% (0.011 g) between the three drivers. The averages of the “rapid” acceleration runs over a distance of 150 ft (45.7 m) were 0.135, 0.134, and 0.127 g for Driver 1, Driver 2, and Driver 3, respectively. The averages of the rapid acceleration runs varied only 6% (0.008 g) between the three drivers. [Table 6](#) and [Table 7](#) showed the calculation of the velocity from [Eq 1](#) in comparison to the value calculated by Vericom. The results showed that for all three drivers, [Eq. 1](#) calculated the vehicle velocity within -6.7% to 8.6% (-.80 mph to 1.73 mph) of the Vericom results for the normal acceleration runs and -7.8% to 6.3% (-0.8 mph to 1.44 mph) of the Vericom results for the rapid runs. As noted, the negative sign in the rapid runs indicated that the calculated vehicle in speed [Eq 1](#) was less than the Vericom. In general, [Eq. 1](#) showed reasonable agreement with the Vericom velocity results.