CALIFORNIA
AIR RESOURCES BOARD

SAE J2982 Zero Emission Motorcycle (ZEM) Range Testing

58th EPPR Informal Working Group
April 12, 2023

Background

- Range is an important metric in measuring the performance of a zero-emission motorcycle (ZEM)
- CARB is developing a credit program to help accelerate adoption of ZEMs
  - Credits will be awarded based, in part, on total range. Therefore, it is critical to have an accurate and repeatable test to quantify total range.
- SAE J2982 *Riding Range Test Procedure for On-Highway Electric Motorcycles* is a procedure for determining the range of ZEMs.
- CARB staff tested three ZEMs following J2982 to gain understanding of what is involved in ZEM range testing and help define criteria of the proposed ZEM regulation.
  - Results may also be useful for development of international ZEM range testing procedures

Testing

- J2982 Involves selecting a drive-cycle, performing a charge/soak for 6-36 hours, and running the ZEM on a dynamometer until it can no long maintain the prescribed drive trace or illuminates a warning light
- 38 tests were run at CARB's Haagen-Smit Laboratory in El Monte, California
  - Testing dates: 01/27/23 – 03/16/23
- Testing consisted of four different drive cycles, at least two runs each:
  - UDDS (US EPA certification cycle), WMTC (sub-class 2-2, 3-1, 3-2), 55 mph constant speed, and 70 mph constant speed
- Some drive-cycles were re-run with alternate dynamometer coefficients, vehicle test weights, or drive-cycle variants to observe test variability.

ZEMs Used for Testing

MODEL YEAR	ZEM	APPROXIMATE BATTERY CAPACITY	APPROXIMATE MOTOR PEAK POWER	APPROXIMATE VEHICLE WEIGHT
2023 (pre-production)	A - Small	4.5 kWh	13.5 kW (18 hp)	125 kg (275 lb)
2023	B - Medium	7 kWh	34 kW (45.5 hp)	136 kg (300 lb)
2023	C - Large	17 kWh	75.0 kW (100 hp)	250 kg (550 lb)

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Dyno Coefficients

- Dynamometer load was set using either EU or US EPA default coefficients based on vehicle mass
  - WMTC = EU coefficients
  - UDDS = US EPA coefficients
  - Constant speed = US EPA coefficients unless otherwise noted

- J2982 also manufacturers may define their own inertia settings based on road load coast-down procedures
  - Coast-down testing was not conducted for this test program, but may be evaluated in a future test program

EU versus US EPA Coefficients

- EU and US EPA have different methods for defining vehicle weight and dyno coefficients, leading to different range results

Example of US EPA Dyno Coefficients
40 CFR § 86.529-98

Loaded vehicle mass (kg)	Equivalent inertial mass (kg)	Force coefficients		Force at 65 km/h (nt)	70 to 60 km/h coastdown calibration times		
		A (nt)	C (nt/(km/h)^2)		Target time (sec)	Allowable tolerance	
						Longest time (sec)	Shortest time (sec)
166–175	170	6.06	.0244	109.0	4.36	4.6	4.2
176–185	180	6.94	.0246	111.0	4.53	4.7	4.3

Example of Euro 5 Dyno Coefficients
134/2014 Appendix V

Table Ap5-1

Classification of equivalent inertia mass and running resistance used for L-category vehicles

Reference mass m_{ref} (kg)	Equivalent inertia mass m_i (kg)	Rolling resistance of front wheel a (N)	Aero drag coefficient b (N/(km/h)^2)
$165 < m_{ref} \leq 175$	170	15,0	0,0226
$175 < m_{ref} \leq 185$	180	15,8	0,0227

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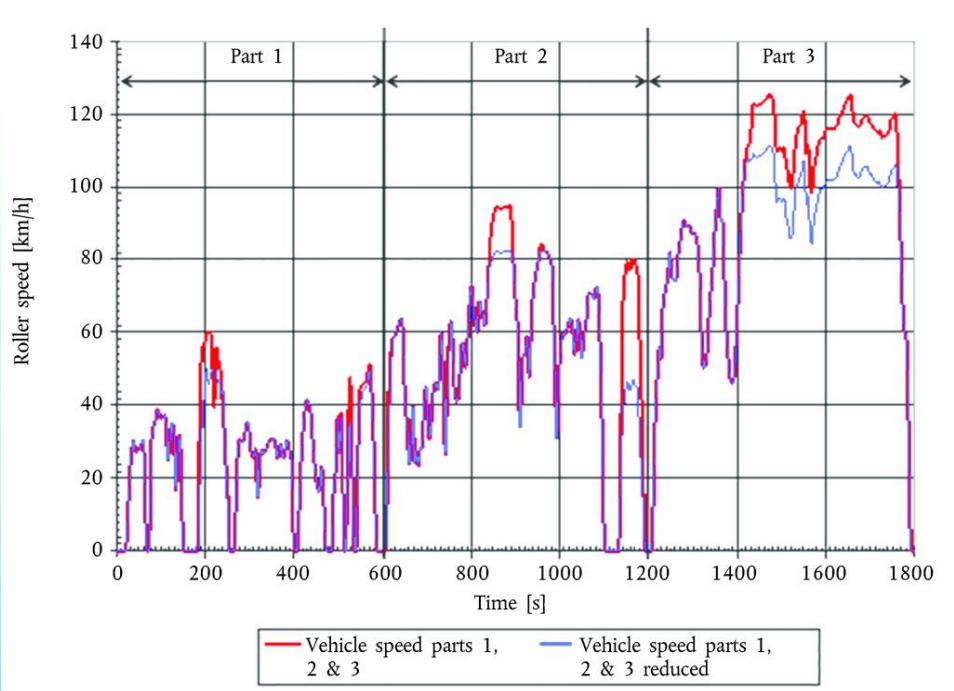
WMTC Sub-Classes

- Different versions of the WMTC are conducted depending on V_{max} and displacement

V_{max}	Sub-class
115 km/h ≤ V_{max}< 130 km/h	2-2
130 ≤ V_{max}< 140 km/h	3-1
V_{max} ≥ 140 km/h	3-2

- Test ZEM A had unknown V_{max}
- Test ZEM B had reported V_{max} of 85 mph (136.8 kph)



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Results: ZEM A (small)

All distances in miles				
Drive Cycle	**Run1**	**Run 2**	**Difference**	**% Difference**
WMTC (2-2)	51.3	51.1	0.20	0.39%
WMTC (3-1)	39.2	38.3	0.90	2.32%
UDDS	53.7	53.7	0.00	0.00%
55mph	32.7	32.5	0.20	0.61%
70mph	12.0	11.8	0.20	1.68%

Results: ZEM B (medium)

All distances in miles				
Drive Cycle	**Run 1**	**Run 2**	**Difference**	**% Difference**
WMTC (3-1)	60.0	60.0	0.0	0.00%
WMTC (3-2)	47.9	NA	NA	NA
UDDS	91.0	90.8	0.2	0.22%
55 MPH (210kg)	48.6	46.3	2.3	4.85%
70 MPH (210kg)	30.7	30.6	0.1	0.33%
70 MPH (220kg)	31.0	30.3	0.7	2.28%

Results: ZEM C (large)

All distances in miles				
Drive Cycle	**Run 1**	**Run 2**	**Difference**	**% Difference**
WMTC (3-2)	105.7	104.6	1.1	1.05%
UDDS	178.8	178.3	0.5	0.28%
55 MPH	105.1	100.9	4.2	4.08%
70 MPH (330)	70.5	69.4	1.1	1.57%
70 MPH (320)(EU)	78.1	77.6	0.5	0.64%

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Comparison of Range Using Different Dyno Coefficients

Below are some examples of the differences observed when ZEMs were run with different Dyno Coefficients on the exact same drive-cycle

TEST BIKE	DRIVE CYCLE	EU (210kg)	US EPA (210kg)	Difference	Difference %
ZEM B	70 MPH	32.8 Miles	30.7 Miles	2.1 Miles	6.61%

TEST BIKE	DRIVE CYCLE	EU (320kg)	US EPA (330kg)	Difference	Difference %
ZEM C	70 MPH	78.1 Miles	70.5 Miles	7.6 Miles	10.23%

Comparison of Range Using Different WMTC Sub-Classes

Below are some examples of the differences observed when ZEMs were run with different WMTC sub-classes

TEST BIKE	WMTC 2-2 (average)	WMTC 3-1 (average)	Difference	Difference %
ZEM A	51.2 miles	38.8 miles	12.4 miles	24.22%

TEST BIKE	WMTC 3-1 (average)	WMTC 3-2	Difference	Difference %
ZEM B	60.0 miles	47.9 miles	12.1 miles	20.17%

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Testing Observations

- Run-to-run variability was generally quite low for all bikes tested
- **UDDS** was the longest test to run due to lower average speeds during testing
  - ZEM C took over 9 hours to complete UDDS testing
- **55 mph** and **70 mph** constant speed tests were the shortest tests to run
- Dyno coefficients and test cycle variants impact range results
  - Potential for misleading information and customer confusion
- Per SAE J2982, constant speed tests can be used in conjunction with the UDDS to calculate a combined city/highway range known as Highway Commuting Range.

$$\text{Highway Commuting Range} = \frac{1}{\frac{0.5}{\text{Range}_{\text{UDDS}}} + \frac{0.5}{\text{Range}_{\text{city constant speed}}}}$$

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Tested Highway Commuting Range

Highway Commuting Range (miles) ZEM A		
UDDS	**55 MPH**	**HCR**
53.7	32.7	40.6
UDDS	**70 MPH**	**HCR**
53.7	12	19.6

Highway Commuting Range (miles) ZEM B		
UDDS	**55 MPH**	**HCR**
91.0	48.6	63.4
UDDS	**70 MPH**	**HCR**
91.0	30.7	45.9

Highway Commuting Range (miles) ZEM C		
UDDS	**55 MPH**	**HCR**
178.8	105.1	132.4
UDDS	**70 MPH**	**HCR**
178.8	70.5	101.1

WMTC vs J2982 HCR Range

Test Bike	WMTC	HCR	Difference	Difference (%)
ZEM A	39.2 (3-1)	40.6 (@55mph)	1.4	3.63%
ZEM B	60 (3-1)	63.4 (@55mph)	-3.4	-5.45%
	47.9 (3-2)	46.2 (@70mph)	1.7	3.51%
ZEM C	105.7 (3-2)	101.1 (@70mph)	4.6	4.42%

- Good correlation between WMTC 3-1 and HCR UDDS + 55 mph test
- Good correlation between WMTC 3-2 and HCR UDDS + 70 mph test
- Could WMTC and HCR results be used interchangeably?
  - WMTC testing takes less time to complete
  - UDDS + constant speed provides more detailed range information broken down by driving type (City, highway, and combined)

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Possible Next Steps

- Test additional ZEMs to confirm results of this test program
- Conduct real world coast-down testing to compare dyno coefficients and corresponding range results with EU and US EPA default values
- Collect real world ZEM range data under a variety of operating conditions to see how it compares with dyno-based range test results

Thank you!