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Cold Weather On-Road Testing of a 2015 Nissan Leaf

Shawn Salisbury

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://avt.inl.gov

SUMMARY

On-road testing of a 2015 Nissan Leaf battery electric vehicle was performed during the winter and spring months of January through May 2016 to determine the impact of cold temperatures on driving efficiency. A single test vehicle was parked and charged in an unsheltered parking stall and was driven along a fixed route by a single driver. The route included a mix of rural, city, and highway roads in the Idaho Falls, Idaho area. On each day of testing, the route was driven multiple times to understand the impact on energy consumption and vehicle range from the vehicle and its components warming up. The vehicle was instrumented to record vehicle network data during driving, and charging energy was captured by the off-board charging equipment.

Ambient temperatures ranged from 11 to 73°F during testing. Electrical energy consumption and driving range varied significantly, depending on temperature. During the coldest temperature, the Leaf completed the route using 467 Wh/mile of direct current electrical energy from the battery. Based on that test and subsequent tests performed that day (which had an average temperature of 14°F), the estimated driving range of the vehicle was 50 miles. As ambient temperature increased, energy consumption tended to decrease, which led to increased driving ranges. The warmest testing period averaged 71°F and the tests resulted in an estimated range of 91 miles. All testing was completed with the vehicle’s climate control set to auto 72°F.

These results provide trends that can be used to guide the expectations of plug-in electric vehicle consumers and advocates and provide a benchmark for research and development efforts.

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1. INTRODUCTION

Idaho National Laboratory tests advanced technology vehicles as part of its management of the U.S. Department of Energy's Advanced Vehicle Testing Activity (AVTA). AVTA is part of the U.S. Department of Energy's Vehicle Technologies Office and it performs benchmark testing of grid-connected vehicles and electric vehicle supply equipment (EVSE) utilized by the vehicles for charging. This report discusses AVTA on-road testing of a 2015 Nissan Leaf during cold weather months.

The Nissan Leaf is a battery electric vehicle that is driven by an electric motor, with all of its energy used during operation being stored in a 24 kWh battery pack. All of the vehicle's accessories, including heating, air conditioning, radio, and lights, are powered by the battery. As the vehicle's only source of energy, the battery pack must be charged from the electric grid in order for the vehicle to operate. When fully charged, the 2015 Nissan Leaf has a range of 84 miles, as estimated by the Environmental Protection Agency [1].

Because of the cost and energy density of current battery technologies, mass-market electric vehicles (like the Leaf) typically have driving ranges of 100 miles or less. The time required to recharge the Leaf also can vary widely (i.e., from 30 minutes to 10 or more hours), depending on the available charging infrastructure. For many new car buyers, limited range and long charging times are the main deterrents for purchasing an electric vehicle.

The energy efficiency of all vehicles is dependent on many factors, including accessory use and ambient temperature. Because of the highly efficient operation of the Nissan Leaf, its sensitivity to these factors is higher than for a conventional vehicle. This is of extreme importance for electric vehicles due to their limited driving range.

In cold temperatures, all vehicles experience efficiency losses due to increased drag and friction in transmission, tires, and other moving or rotation components. These losses are most prevalent when the vehicle and its components are cold after being left to soak in the ambient conditions. After driving begins, the affected components begin to warm up and efficiency increases. The energy efficiency of electric vehicles is especially sensitive to ambient temperature. Batteries tend to exhibit increased resistance at cold temperatures, which causes lower efficiency and decreased power capabilities. Additionally, climate control is often used for heating and defrosting the cabin, which increases energy consumption from the battery.

To minimize the effect of climate control use on vehicle range, the 2015 Nissan Leaf gives the driver the option to precondition the cabin by using the "Climate Control Timer" setting. With this setting, the vehicle cabin can be heated or cooled prior to departure. If the vehicle is plugged in while the cabin is preconditioning, it will use energy from the grid instead of depleting the battery.

A test plan was developed to understand the effect of temperature on the energy efficiency and range of a 2015 Nissan Leaf and how those results are affected by cabin preconditioning.

2. PROCEDURES AND METHODS

The testing regime specified that a single driver repeatedly drive a single 2015 Nissan Leaf (shown in Figure 1) on a prescribed route on numerous days with varying ambient temperature. The vehicle was parked and charged in an unsheltered parking stall and began each testing period fully charged. Each day, the driver completed two or more tests (one test is defined as one lap around the prescribed route). Data were collected to quantify vehicle efficiency on a per-mile basis and allow for extrapolation of the total driving range. The vehicle controller area network (CAN) was instrumented with data logging equipment to record energy consumption, distance driven, and other parameters. Ambient temperature was logged by a measurement device located at the vehicle's parking location. The driver also recorded data provided by the Leaf's instrument panel at the start and end of each test.

Figure 1. 2015 Nissan Leaf at Idaho National Laboratory.

2.1 Test Route

A route on public roads in the Idaho Falls, Idaho area was selected and included a mix of city, rural, and highway driving. The route was 8.6 miles and started and ended at the Leaf's overnight parking location. The route was not intended to mimic any standardized test cycle. The posted speed limit along this route ranged from 25 to 65 mph. Figure 2 shows a speed trace from a single test that was chosen at random.

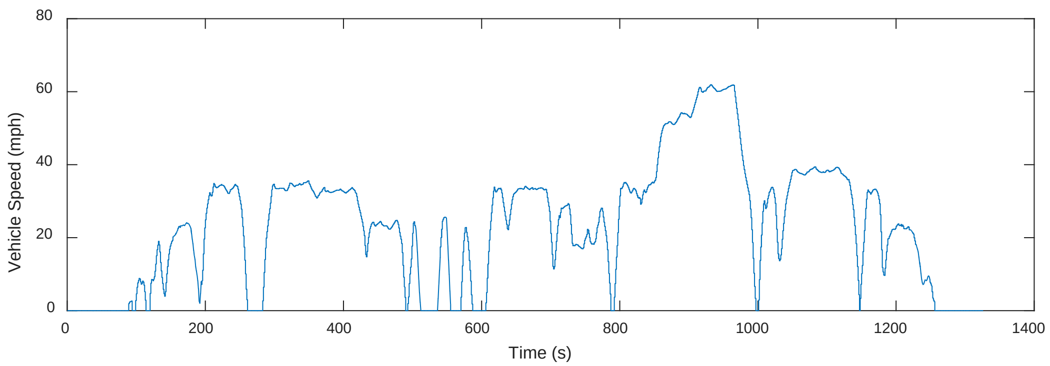

Figure 2. A typical profile of vehicle speed versus time for the Idaho Falls cold weather test route.

To reduce the variation in efficiency that is due to changing driving style or aggressiveness, a single driver performed all vehicle testing. The driver was instructed to accelerate and brake mildly and cruise within 2 mph above or below the posted speed limit. Occasionally, traffic required the driver to slow his speed below this tolerance.

2.2 Startup and Shutdown Procedure

Prior to starting the first test of the day, the vehicle windows were cleared of snow and ice if necessary. At the scheduled start time, the vehicle was unplugged from the charging equipment and was turned on. After the vehicle was on, the front and rear defrosters and headlights were turned on. The driver then recorded pertinent information displayed on the dashboard. If necessary, the driver waited for the windshield to defog; otherwise, the climate control was set to "Auto" and the temperature set to 72°F. It was rarely necessary to wait for the defroster to clear the windshield; the waiting period on these days were less than 1 minute. The drive was then performed, and upon returning to the parking space at the end of the first test, the driver recorded the trip-end metrics and the car was turned off.

The vehicle was left off for 5 minutes, before the drive was performed again. For each subsequent drive, the climate control was set to "Auto" and 72°F. At the conclusion of the final test lap of the day, the vehicle was plugged into an alternating current (AC) Level 2 EVSE and charging began immediately upon plugging in. If use of the climate control timer was planned for the next test, the setting was programmed prior to the start of charging.

2.3 Vehicle Settings and Conditions

The following list describes the settings and conditions for all tests:

- A single driver performed all tests. There was no cargo in the vehicle.
- Cruise control was prohibited during all tests due to the possibility of icy roads on days below freezing and for consistent driving style for tests performed when ambient temperatures were above freezing.
- No accessories other than the climate control system and headlights were used during testing.
- Prior to the first test in January 2016, tire pressure was set to the manufacturer's recommended inflation pressure of 36 psi. This was done after the car had soaked outside for more than 24 hours. The ambient temperature at this time was approximately 25°F.
- Testing was only performed on days when the road was clear of snow or slush.
- Electric seat and steering wheel heaters were always turned off during testing.

2.4 Cabin Preconditioning

The 2015 Nissan Leaf is equipped with a "Climate Control Timer" setting to precondition the air in the vehicle cabin prior to driving. According to the 2015 Nissan Leaf owner's manual, the cabin "Climate Control Timer" operates the climate control system to condition the air to reach a factory preset temperature by a user-programmed departure time. The factory preset temperature for the "Climate Control Timer" was not specified in the vehicle owner's manual or other available documentation.

To better understand the "Climate Control Timer," an observation was performed with the vehicle parked in a laboratory at Idaho National Laboratory at an ambient temperature of approximately 72°F. Approximately 30 minutes prior to the programmed time, the vehicle's heater was automatically switched on. The heater continued to operate until approximately 5 minutes prior to the programmed time, at which point, the climate control switched to the defrost setting. The vehicle continued to defrost until the programmed time, when the climate control system turned off.

When the "Climate Control Timer" was used during testing, the departure time was set for the test time planned for the next day. The vehicle remained plugged in until the set test time, at which point the startup procedure was initiated.

2.5 Data Acquisition

Data were logged from the Leaf's CAN bus during drive testing using a neoVI Fire logger unit. The vehicle was charged using a pedestal-mounted Blink AC Level 2 EVSE (Figure 3). Idaho National Laboratory researchers did not instrument the EVSE to collect charging data; however, reports on energy consumed during charging events were available from the Blink Network website.

A HOBO Pendant ambient temperature data logger was mounted in a solar shield on the side of the EVSE pedestal. The solar shield can be seen in Figure 3.

Figure 3. Blink EVSE used during testing, with an attached solar shield for the temperature logger.

3. RESULTS AND ANALYSIS

3.1 Driving Results

Variations in traffic flow, timing of traffic signals, and other factors caused variation in the profile of speed versus time from test to test. Table 1 provides summary metrics that characterize the test route and variation from test to test.

Table 1. Test time and speed summary statistics.

	Trip Time (minutes)	Average Speed (mph)	Average Nonzero Speed (mph)	Maximum Speed (mph)
Minimum	17.8	22.5	28.6	61.4
Median	19.8	25.9	30.3	62.4
Maximum	22.9	28.7	31.8	67.9
Mean	19.8	25.9	30.2	62.6
Standard deviation	1.2	1.5	0.7	1.1

Between January 21 and May 3, testing was performed on 18 separate days and included 52 completed test laps. Each test day included three test laps, except for two days when only two laps were completed. The first test lap of each day is considered a "cold start," and each subsequent lap is a "hot start." For each lap, energy use was calculated from logged data to determine the amount of direct current (DC) electrical energy used per mile of driving. For each test lap, ambient temperature data collected from the vehicle's CAN bus was averaged over the testing period to determine each lap's average ambient temperature. The results from each test lap are shown in Figure 4.

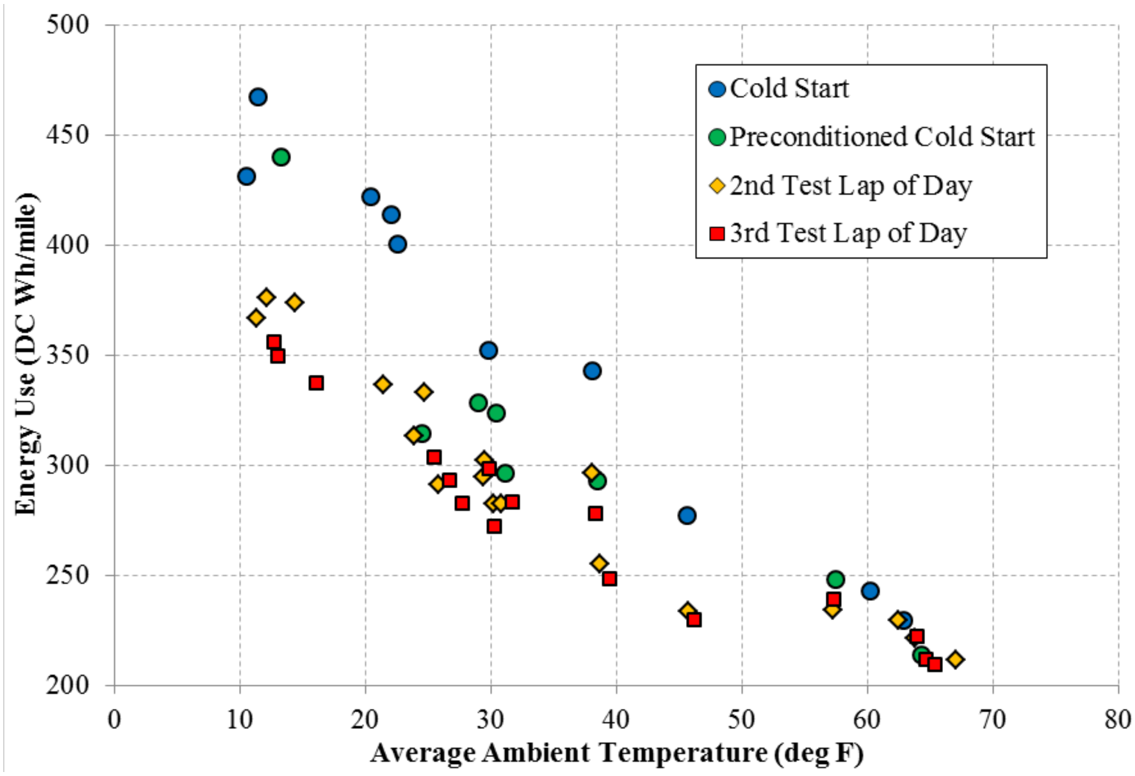

Figure 4. Energy use for each test lap versus average ambient temperature.

Colder ambient temperatures result in higher energy use than warmer temperatures. This was expected due to the increased drag and friction experienced by cold vehicle components and increased climate control loads. One of the coldest cold starts used 467 DC Wh/mile at 11°F, which is more than twice the energy consumption of the warmest cold start at 63°F with 229 DC Wh/mile.

The difference between cold starts and hot starts is more pronounced at colder temperatures than at warmer temperatures. Cold starts at temperatures 30°F and below use as much as 100 DC Wh/mile more energy than their hot start counterparts. As ambient temperature rises, the differences between cold starts and hot starts are minimized. Around 70°F, it is difficult to determine any difference between cold and hot starts.

If testing were performed at temperatures lower than 10°F, it is assumed that energy consumption would continue to increase. A similar result would also be expected if testing were performed at 75°F or greater. At higher temperatures, the vehicle cabin would begin to require cooling to maintain a 72°F cabin, which would increase the vehicle's energy consumption. Testing at 72°F would be expected to approximate the minimum energy consumption for this testing regimen.

Cold starts are broken into two groups based on whether or not the cabin preconditioning setting was used prior to each start. Most of the preconditioned cold starts used significantly less energy than non-preconditioned cold starts at similar temperatures. At temperatures above 55°F, there was no noticeable energy use benefit from cabin preconditioning.

3.2 Driving Range Results

To understand the effect of temperature on the Leaf's driving range, a single charge driving range was estimated for each of the 18 days of testing. This was done using a cycle weighting method similar to that of the Society of Automotive Engineers J1634 standard. For this method, multiple drive cycles are driven and the first drive cycle (i.e., cold start) is weighted differently than subsequent hot start cycles due to the differences in energy use between cold and hot starts. This weighting method is shown in the following equations, where subscripted numbers represent the order of the test laps:

$$K_1 = \frac{Energy\ Used_1}{Usable\ Battery\ Capacity} \tag{1}$$

$$K_2 = K_3 = \frac{(1-K_1)}{2} \tag{2}$$

$$Per\ Mile\ Energy\ Use = K_1 * Energy\ Used_1 + K_2 * Energy\ Used_2 + K_3 * Energy\ Used_3 \tag{3}$$

$$Single\ Charge\ Range = \frac{Usable\ Battery\ Capacity}{Per\ Mile\ Energy\ Use} \tag{4}$$

Driving ranges calculated for each test day are shown in Figure 5. Based on previous testing of a 2013 Nissan Leaf, which has a battery pack identical to that of the 2015 Leaf, the usable battery capacity was assumed to be 19.5 kWh [2]. The temperature shown for each day was the average temperature logged from the vehicle CAN bus during the driving segments of that day.

At about 66°F, the Nissan Leaf had an estimated driving range of 93 miles. As temperature decreased, the driving range decreased at a fairly linear rate of approximately 0.7 miles per degree Fahrenheit. On the coldest days, where ambient temperature was around 12°F, the calculated driving range was just over 50 miles. In general, days when cabin preconditioning was used resulted in a higher driving range than days without preconditioning. When temperatures were 45°F or less, driving range was increased approximately 2 to 7 miles with preconditioning. At temperatures of 55°F or greater, there was little difference between days with and without cabin preconditioning. This is to be expected because of the smaller temperature differential the cabin preconditioning has to make up, making it less of a potential benefit. Interestingly, there was little benefit seen from cabin preconditioning at very cold temperatures, where the potential benefit would seem to be the greatest. On the coldest day with cabin preconditioning, it was determined that the preconditioning event was not sufficient to fully precondition the cabin; therefore, the heating loads during testing were similar to what could be seen on a slightly warmer day without preconditioning.

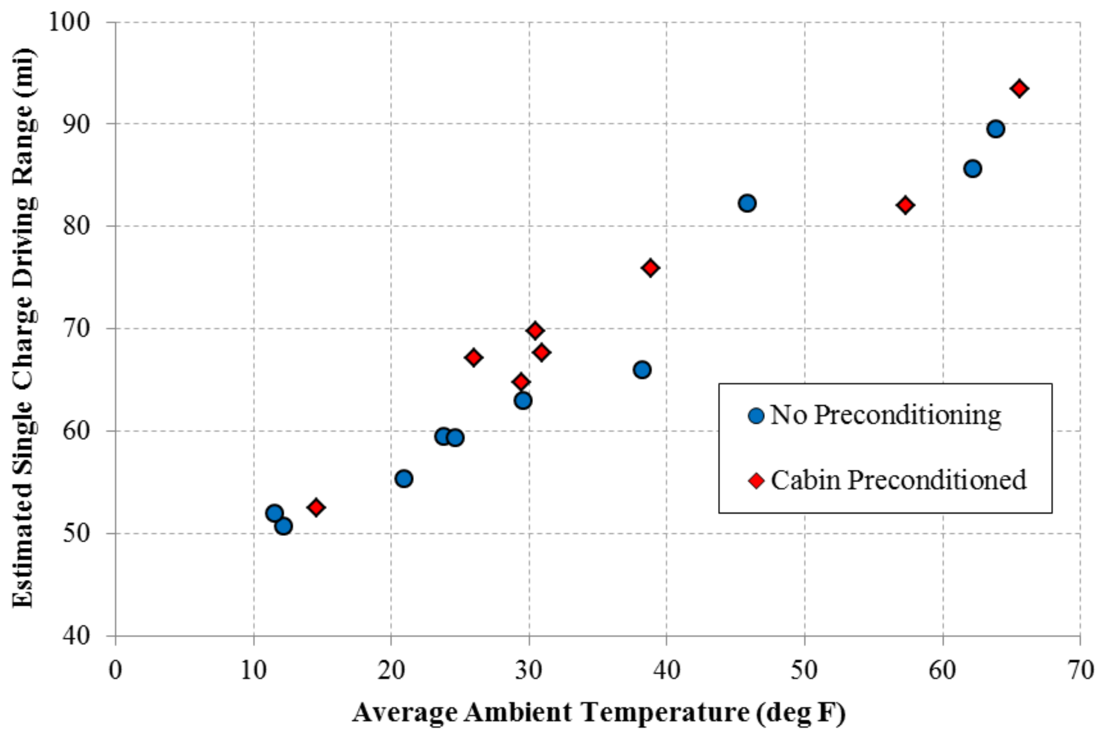

Figure 5. Estimated driving range at different ambient temperatures.

3.3 Cabin Preconditioning Events

For each preconditioning event, energy use and duration were collected and were available from the Blink network. Data from the Blink network included duration and energy consumption of each event; ambient temperature was captured by the HOBO Pendant logger.

After inspecting data from preconditioning events, it was clear that energy use during each event was different depending on ambient temperature. Two events occurred when ambient temperatures were greater than 60°F and each consumed approximately 650 AC Wh over 30 minutes. In Section 3.2, it was determined that there was little difference in driving range between preconditioned and non-preconditioned days at these temperatures, meaning that energy consumed by preconditioning contributed solely to passenger comfort.

Five events were captured at ambient temperatures between 10 and 40°F. Energy use during these events ranged from 1,100 to 2,200 AC Wh and event time ranged from 32 to 55 minutes. The causes of variations in time and energy use are not known.

4. CONCLUSION

A 2015 Nissan Leaf was tested between February and May 2016 to understand the effects of cold weather on the vehicle's energy consumption. The Leaf was tested on 18 days, with 52 laps of a fixed route being completed by a single driver. The route consisted of city, highway, and rural roads in Idaho Falls, Idaho. For each day of testing, the test route was driven 2 or 3 times. Throughout the test period, the vehicle was parked and charged with an AC Level 2 EVSE in an open air parking space.

Ambient temperature during testing ranged from 11 to 67°F. One of the coldest test laps had an energy use of 467 DC Wh/mile, which was 122% more energy than the 210 DC Wh/mile used during the warmest lap. At colder temperatures, cold starts used much more energy than hot starts and at warmer temperatures, there was little difference seen between cold and hot starts. On all test days, the driving range of the Leaf was extrapolated from the test laps performed that day. Results showed that the colder the ambient temperature was during testing, the shorter the driving range. Above 70°F, the driving range was calculated to be over 90 miles and at 14°F, range dropped to 51 miles (i.e., a reduction of 45%).

Using the cabin preconditioning setting of the 2015 Leaf led to increased driving ranges when compared to days where preconditioning was not used, especially at temperatures lower than 45°F. At colder temperatures, driving range increased by approximately 2 to 7 miles when preconditioning was used. However, at temperatures greater than 55°F, preconditioning had little effect on energy consumption or driving range.

These results do not capture the entire range of cold weather effects on the 2015 Nissan Leaf. Results can vary significantly based on many factors, including driving style, climate control settings, and environmental conditions. However, the results do demonstrate a significant trend of increased energy consumption and decreased driving range at colder temperatures. These trends are useful for providing consumers, advocates, and researchers with reasonable performance expectations of electric vehicles operating in cold temperatures.

5. REFERENCES

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