

Analysis Reveals Impact of Road Grade on Vehicle Energy Use

Highlights in
Research & Development

Findings indicate that, on average, road grade could be responsible for 1%–3% of fuel use in light-duty automobiles, with many individual trips impacted by as much as 40%.

Understanding the power demands of modern automobiles is essential for designing increasingly efficient powertrains. In recent years, the advent of ubiquitous global positioning systems has made large-scale data collection of vehicle speed and associated power demand a reality. While the availability of such real-world data has improved industry's understanding of in-use vehicle power demands, little attention has been paid to the incremental energy requirements imposed by road grade—until now.

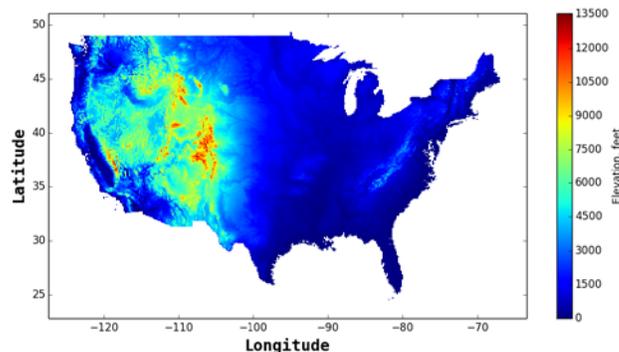
With funding from the U.S. Department of Energy's Vehicle Technologies Office, engineers from the National Renewable Energy Laboratory (NREL) performed an analysis quantifying the incremental efficiency impacts of road grade by appending high-fidelity elevation profiles to GPS speed traces. This in-depth study employed nationwide elevation data from a U.S. Geological Survey digital elevation model as well as detailed GPS data from NREL's Transportation Secure Data Center with drive cycles from more than 250,000 unique trips in various metropolitan areas across the country.

Using NREL's Future Automotive Systems Technology Simulator (FASTSim), the team performed vehicle powertrain simulations with and without road grade for five vehicle models—conventional, hybrid, and all-electric mid-sized cars and conventional and hybrid SUVs. Aggregate results of the study suggest that, on average, road grade could be responsible for 1%–3% of fuel use in light-duty automobiles. Variation from the average can be quite significant for individual trips, with many uphill trips using as much as 15%–40% more fuel and many downhill trips using as much as 10%–35% less fuel than if grade was not considered. In particular, the simulated hybrid and all-electric vehicles experienced greater variation in fuel penalty on a percentage basis due to their nominally lower energy consumption rates.

On the other hand, the simulated conventional vehicles experienced average grade penalties 25%–73% greater than their hybrid and all-electric counterparts. These differences are likely due to the regenerative braking systems in hybrid and all-electric vehicles, which can capture energy on a downhill for later use, and the ability of these vehicles to eliminate idle fuel use during low-power downhill driving. This previously nonexistent data is expected to aid in the design of powertrain components by providing anticipated operating envelopes based on real-world data inclusive of road grade.

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Reference: Wood, E.; Burton, E.; Duran, A.; Gonder, J. (2014). "Contribution of Road Grade to the Energy Use of Modern Automobiles Across Large Datasets of Real-World Drive Cycles." Preprint. Prepared for the SAE World Congress, April 8–10, 2014. NREL/CP-5400-61108. Golden, CO: National Renewable Energy Laboratory. www.nrel.gov/docs/fy14osti/61108.pdf.



Color plot showing elevation values for the contiguous United States. Source data derived from the USGS digital elevation model, which features precise, validated elevation data at 10-meter intervals—resulting in about 800 billion data points.

Key Research Results

Achievement

A new study sheds light on the incremental energy requirements imposed by road grade.

Key Result

Aggregate results of this study suggest that road grade could be responsible for 1%–3% of fuel use in light-duty automobiles, with conventional vehicles falling on the higher end of this range and hybrid and all-electric vehicles falling on the lower end. On the individual trip level, hybrid and all-electric vehicles can experience more extreme fuel efficiency impacts than their conventional counterparts.

Potential Impact

Understanding the real-world power demands of modern automobiles is essential for designing increasingly efficient powertrains. Road grade has the potential to dramatically influence energy consumption by inducing hill climbs that require additional power and/or descents that could be leveraged by regenerative braking systems to improve efficiency.

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

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