

Hydraulic Hybrid and Conventional Parcel Delivery Vehicles' Measured Laboratory Fuel Economy on Targeted Drive Cycles

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ABSTRACT

This research project compares laboratory-measured fuel economy of a medium-duty diesel powered hydraulic hybrid vehicle drivetrain to both a conventional diesel drivetrain and a conventional gasoline drivetrain in a typical commercial parcel delivery application. Vehicles in this study included a model year 2012 Freightliner P10HH hybrid compared to a 2012 conventional gasoline P100 and a 2012 conventional diesel parcel delivery van of similar specifications.

Drive cycle analysis of 484 days of hybrid parcel delivery van commercial operation from multiple vehicles was used to select three standard laboratory drive cycles as well as to create a custom representative cycle. These four cycles encompass and bracket the range of real world in-use data observed in Baltimore United Parcel Service operations. The New York City Composite cycle, the City Suburban Heavy Vehicle cycle, and the California Air Resources Board Heavy Heavy-Duty Diesel Truck cycle as well as a custom Baltimore parcel delivery cycle were tested at the National Renewable Energy Laboratory's Renewable Fuels and Lubricants Laboratory. Fuel consumption was measured and analyzed for all three vehicles. Vehicle laboratory results are compared on the basis of fuel economy. The hydraulic hybrid parcel delivery van demonstrated 19%-52% better fuel economy than the conventional diesel parcel delivery van and 30%-56% better fuel economy than the conventional gasoline parcel delivery van on cycles other than the highway-oriented HHDDT cycle.

CITATION: Lammert, M., Burton, J., Sindler, P., and Duran, A., "Hydraulic Hybrid and Conventional Parcel Delivery Vehicles' Measured Laboratory Fuel Economy on Targeted Drive Cycles," *SAE Int. J. Alt. Power.* 4(1):2015, doi:10.4271/2014-01-2375.

INTRODUCTION

Hybrid drivetrains have shown significant promise as part of an overall petroleum reduction fleet strategy [1, 2, 3, 4, 5, 6]. Hybrid drivetrains consist of an energy storage device and a motor integrated into a traditional powertrain and offer the potential fuel savings by capturing energy normally lost during deceleration through the application of regenerative braking. Because hybrid technologies, especially hydraulic hybrids, have low adoption rates in the medium-duty vehicle segment and because fuel savings from hybrids are highly dependent on the duty cycle they are driven on, there are still questions to be answered about when and where this technology offers a valuable return on investment in the form of fuel savings as well as which type of system works best in this application.

The objective of this project was to evaluate the in-use fuel economy of a hydraulic hybrid vehicle (HHV) compared to two conventional powertrain options operating over a range of representative standard chassis test duty cycles through chassis dynamometer testing under laboratory conditions.

Background and Methods

United Parcel Service (UPS) placed 20 new Parker Hannifin infinitely variable transmission (IVT) hydraulic hybrids into service in the Baltimore area in November 2012 as part of a purchase of 40 new HHV parcel delivery vans. These HHVs include an "engine off at idle" function and meet 2010 emissions standards. UPS also deployed gasoline-powered conventional parcel delivery vans around the same time to the Baltimore depots. Because UPS moved to using a gasoline engine in this application as the standard specification, no diesel vehicles were available within the Baltimore fleet; therefore, a diesel-powered conventional vehicle of similar specification was secured from an alternative parcel delivery van fleet for laboratory testing. The National Renewable Energy Laboratory (NREL) also evaluated hybrid electric vehicles (HEVs) in UPS service in this class of parcel delivery van previously in Phoenix, Arizona, and Minneapolis, Minnesota [3, 4, 5, 6].

Vehicle Selection and Details

The Parker Hannifin IVT HHV was compared to the UPS standard gasoline conventional drivetrain as well as a conventional diesel drivetrain commonly used for this

vocational application. Table 1 lists the vehicles' specifications. The HHV uses a 280 HP ISB calibration instead of a 200HP calibration used in the diesel conventional because that was the only calibration being offered for hybrid applications by Cummins. The payload estimate used for testing is the result of discussions with UPS as an average daily load and is directly comparable to a previous dynamometer test series [3, 6].

Table 1. Study van details

Parcel Delivery Van Specification	Conventional Diesel Van	Conventional Gasoline Van	Hydraulic Hybrid Van
Chassis Manufacturer	Freightliner	Workhorse W62	Freightliner
Van manufacturer	Utilimaster Corp.	Morgan Olson	Morgan Olson
Van model	NA	P100	P10HH
Van model year	2011	2012	2010
Engine manufacturer	Cummins	GM	Cummins
Engine model	ISB	LQ4	ISB
Engine power rating	200 HP	299 HP	280 HP
Engine displacement	6.7L	6.0L	6.7L
Engine model year	2012	2012	2012
Emissions equipment	DPF, SCR	3 way catalyst	DPF, SCR
Transmission	Allison Automatic	Automatic	Parker Hannifin IVT
Retarder/regenerative braking	None	None	Regenerative Braking
Air conditioning type	None	None	None
Gross vehicle weight rating	19,500 lbs	23,000 lbs	23,000 lbs
Vehicle Test Weight	15,410 lbs.	14,160 lbs.	18,015 lbs.
Payload for Testing	4,000 lbs.	4,000 lbs.	4,000 lbs.

Table 2 lists pertinent Parker Hannifin IVT hydraulic hybrid system details. This system is a "powersplit," or a combination of parallel and series in architecture. It is a dual path system capable of transmitting power hydraulically or mechanically or a combination of both. The system uses a gear box to mix power input from both the diesel engine and the hydraulic motor to the wheels, to the hydraulic motor from the wheels for regeneration or from the hydraulic motor to the engine flywheel to start the engine. The system also shuts off the diesel engine when it is not needed. According to Parker Hannifin, the system supplies 100% of the power hydraulically from a stop and ramps down to less than 10% of power transmitted hydraulically at 30 mph with a 50% mechanical / hydraulic pathway split at 15 mph. This system is intended to capture energy during slow speed stop-and-go driving, but to provide for mechanical power transmission at higher speeds.

Table 2. Hybrid system details

Category	Hybrid System Description
Manufacturer/integrator	Parker Hannifin Corporation
Transmission	Parker IVT
Drive mode max power	200 HP
Brake mode max power	200 HP
Energy storage	22 gallon accumulator
	3,500–4,000 psi nominal pressure range
	5,400 psi max pressure

Duty-Cycle Analysis and Test Cycle Selection and Creation

GPS and J1939 Vehicle Data Logging

Isaac Instruments DRU900/908 data logging devices with global positioning system (GPS) antennas and J1939 controller area network (CAN) bus connections were deployed to the UPS Baltimore fleet to collect operational data. This information was combined with a month of telematics data provided by Parker Hannifin from systems already installed on the Baltimore HHVs. In total, 484 vehicle days of HHV operation on 20 parcel delivery vans were documented. The GPS and J1939 channels collected as part of this project were recorded at a 1-Hz sampling rate. J1939 controller area network bus channels collected included wheel-based vehicle speed, engine speed, and engine fuel rate among others (see Appendix Table A1 for a complete list). The same data collection devices and channel settings (minus GPS) were used during laboratory dynamometer testing to capture vehicle systems activity during the test runs.

Data Analysis Using DRIVE™

Filtration and analysis of the 484 days of in-use field data collected as part of the study were performed using NREL's Drive-Cycle Rapid Investigation, Visualization, and Evaluation (DRIVE™) analysis tool [7, 8]. Employing NREL's DRIVE analysis tool, researchers were able to explore daily vehicle operation and ensure data quality through analysis of approximately 150 drive cycle metrics calculated by the tool. The 150 drive cycle metrics calculated ranged in scope from high-level route descriptors such as average driving speed (mph) and stops per mile, down to vehicle energy level metrics such as kinetic power density consumed (W/kg) and kinetic intensity (1/mile), most of which were calculated using different formulations of the fundamental road load equation [9]. When performing the road load equation calculations, it was assumed the effects of road grade were negligible. However, road grade effects and their contributions to vehicle power demand have been explored in prior research, and associated fuel economy penalties have been documented [10, 11].

Laboratory Standard Test Cycle Selection

In an effort to select standard chassis test cycles that reflect the aggregate in-use data, a multivariate least squares selection method was employed. Through a comparison of drive cycle metrics such as average driving speed, stops per mile, and others, a representative set of test cycles was chosen representing the range of driving conditions. The corresponding cycles chosen to bracket and represent the range of driving observed were the California Air Resources Board (CARB) Heavy Heavy-Duty Diesel Truck (HHDDT), City Suburban Heavy Vehicle Cycle (CSHVC), and New York City Composite cycle (NY Comp). (See Appendix Figures A1, A2, A3 showing the cycles).

DRIVE™ Custom Test Cycle Generation

The DRIVE tool employs a deterministic multivariate hierarchical clustering method to generate representative drive cycles from source data [12]. Starting with source in-use data, the tool generates representative cycles of user-specified durations by first analyzing the drive cycle characteristics of a composite “super” cycle containing the driving profile of each input drive cycle concatenated together. In generating a composite cycle this way, time-based weighting is achieved, with the duration of each source cycle influencing the underlying metrics of the composite “super” cycle, as opposed to the common approach of non-weighted averages being computed from a set of cycle metrics representing each source cycle. The non-weighted approach can result in composite cycles that can disproportionately weight the metrics of the composite cycle toward the components with short durations. Once the “super” cycle has been characterized over more than 150 drive cycle metrics, the tool then decomposes the composite cycle into its component microtrips, which are individually analyzed over the same set of operational drive cycle metrics. This set of statistics includes well-known metrics such as average driving speed, stops per mile, and zero speed time as a percentage of cycle operation, as well as specialized metrics such as kinetic intensity, aerodynamic speed, and characteristic acceleration, which are used to characterize energy consumption [8]. Having been characterized, the individual microtrips undergo an iterative multivariate k-means clustering process in which they are grouped into clusters and ranked based on a set of predefined performance metrics. Upon ranking, the ideal microtrip from each cluster is selected and concatenated to form a representative cycle. This clustering process is iterated over a chosen number of clusters, with the upper limit on the number of clusters calculated as the product of the desired representative cycle duration, the number of stops per mile for the “super” cycle, and the average speed over the “super” cycle. As a final step in the generation of a representative drive cycle, zero speed time is either added or removed from the final drive cycle output to match the percentage found in the original data “super” cycle. (See Appendix [Figure A4](#) showing the cycle).

Laboratory Chassis Dynamometer Testing Procedures

Dynamometer testing methods recommended in SAE J2711 “Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional Heavy-Duty Vehicles” [12] were used as a guide. Vehicles are secured to the dynamometer with the drive axle(s) over the rollers. The vehicle is driven by a driver following a prescribed speed trace that is defined by the previously selected/generated drive cycles. A three-foot diameter 2-HP fan is used to force cooling air onto the test vehicle's radiator to simulate the ram cooling effect of a vehicle in motion. Emissions measurements are

collected from the exhaust dilution system for analysis, and various vehicle parameters (J1939) are monitored and logged by the Isaac DRU908 data acquisition system.

To assure the accuracy and consistency of road load simulation used during chassis dynamometer testing, the dynamometer is subjected to various procedures and checks. The daily testing routine consists of the following steps: 1) In the morning, the vehicle is lifted off the rollers, and the dynamometer is subjected to a warm-up procedure until the parasitic losses stabilize. 2) The unloaded coastdown procedure is used to verify that the parasitic losses did not change from previous testing and that load cell calibration has not drifted. 3) Following this verification, the vehicle is placed back on the rollers and driven for 20 minutes to warm up. 4) A conditioning test run is performed to stabilize the vehicle's temperature over the test cycle. 5) After the warm-up cycle the dynamometer road load simulation is verified via loaded coastdown. Once the road load is verified as accurate, testing can start. 6) Test runs are considered usable provided the road load simulation proves consistent in the previous step. This is verified after each test. To maximize consistency, the soak period between engine-off of one test and engine-on of the following is kept at 20 minutes.

Emissions Measurement

The emissions measurement system at the NREL Renewable Fuels and Lubricants Laboratory is designed based on Code of Federal Regulations Section 40, Part 86, Subpart N. The system consists of a full flow dilution tunnel with a constant volume sampling system for mass flow measurement. The tunnel flow rate is measured and controlled using critical flow venturis. The dilution and engine combustion air is supplied by an air handling unit that maintains the desired air temperature, pressure, and humidity and is HEPA filtered.

Gaseous exhaust emissions are analyzed by a Horiba MEXA 7100 series system which includes measurements of total hydrocarbons, oxides of nitrogen (NO_x), carbon monoxide, and carbon dioxide. The gas analytical system was verified prior to beginning the testing period, including linearization checks and a NO_x converter efficiency test. On a daily basis, the analyzers are zero and span calibrated, and each test was bracketed by zero, span, and background readings used for corrections. The emissions measurement data are then reduced to distance specific mass results using the Code of Federal Regulations-recommended calculations, including humidity, dry to wet, zero, span, and background corrections.

Fuel Consumption Measurement

The primary fuel consumption measurement approach applied in this project was gravimetric-based analysis. Engine fuel supply and return lines were connected to a fuel container placed on a scale, where scale mass measurements were collected and recorded in real time along with all the test data.