

2018 Toyota UB80E Automatic Transmission - NCAT Test Report

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# Purpose of Test

The purpose of this testing is to characterize the performance of a 2018 Toyota UB80E Direct Shift eight-speed automatic transaxle with sequential shift mode used in a Toyota Camry. The testing was conducted to evaluate and measure results for transmission gear efficiencies, idle fuel consumption, torque converter K-factors and to generate a torque loss map. Results of this study may also be used in the ALPHA (Advanced Light-Duty Powertrain & Hybrid Analysis) model.

# Definitions

|  |  |
| --- | --- |
| Controller Area Network (CAN) | Vehicle bus standard designed to allow various controllers and devices to communicate with each other |

# Description of Test Article

A 2018 Toyota Camry built with a 2.5L engine and UB80E eight-speed automatic transaxle was selected for use in this testing. Table 1 describes the vehicle and powertrain used in this test program.

**Table 1: Summary of Vehicle and Powertrain Identification Information**

|  |  |
| --- | --- |
| Vehicle (Model Year, Make, Model) | 2018 Toyota Camry |
| Vehicle Identification Number | JTNB11HKXJ3007695 |
| Engine (Displacement, Name) | 2.5L A25A-FKS Four-Cylinder |
| Rated Power | 151 kW @ 6600 RPM |
| Rated Torque | 249 Nm @ 4800 RPM |
| Recommended Fuel | 87 Octane Anti-Knock Index (AKI) |
| Transmission | UB80E Eight-speed Automatic Transaxle |

The UB80E is a front-wheel drive eight-speed automatic transmission described as a Direct Shift 8‑speed ECT‑i automatic with sequential shift mode and a torque capacity of 280 Nm. The gear ratios for the UB80E transmission are provided in Table 2.

**Table 2: Transmission Gear Ratios**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Gear** | **1st** | **2nd** | **3rd** | **4th** | **5th** | **6th** | **7th** | **8th** | **Rev** | **Diff** |
| Ratio | 5.250 | 3.028 | 1.950 | 1.456 | 1.220 | 1.000 | 0.808 | 0.673 | 4.014 | 2.802 |

# Test Site

This test was performed in National Center for Advanced Technology (NCAT) Test Cell 9, but the procedure is applicable to any NCAT test cells using iTest controls and RPECS data collection.

# Test Cell Capabilities

The following instrumentation, listed in Table 3, exists in Test Cell 9 although not all instrumentation listed may have been utilized during this testing.

**Table 3: Instrumentation in NCAT Test Cell 9**

|  |  |  |
| --- | --- | --- |
| Instrument Name | Purpose/Measurement Capabilities | Manufacturer |
| Dynamometer | Engine speed, torque, power | Meidensha |
| Torque Sensors | In-line shaft torque | HBM |
| CVS dilution tunnel | Dilution, exhaust flow | EPA |
| Coriolis fuel meter | Fuel flow rate | Micromotion |
| Laminar flow element | Air flow rate | Merriman |
| Methane cutter | Remove methane | Horiba |
| Emissions bench | Raw and dilute exhaust gases:  CO, THC, NOx, CH4, CO2 | MEXA |

# Data Collection Systems

Test cell data acquisition and dynamometer control are performed by iTest, a software package developed by A&D Technology, Inc. Test cell data including temperatures, pressures, speed and torque are logged by iTest. Engine and transmission ECU inputs and outputs are measured using the Rapid Prototyping Engine Control System (RPECS), a hardware/software package for engine control and supplemental data acquisition developed by Southwest Research Institute (SwRI). RPECS data is logged by iTest via an Ethernet connection and combined into a single output file. The transmission control and analysis software packages are summarized below in Table 4.

**Table 4: Test Control and Analysis Software**

|  |  |  |  |
| --- | --- | --- | --- |
| Software | Developer | Description | Data Rate |
| iTest | A&D Technology, Inc. | Controls the dynamometer; collects test cell data; master data logger; commands pedal | 10 hz |
| RPECS | Southwest Research Institute | Collects TCU, CAN and analog transmission data; controls torque converter lock up solenoid | 1/engine cycle |

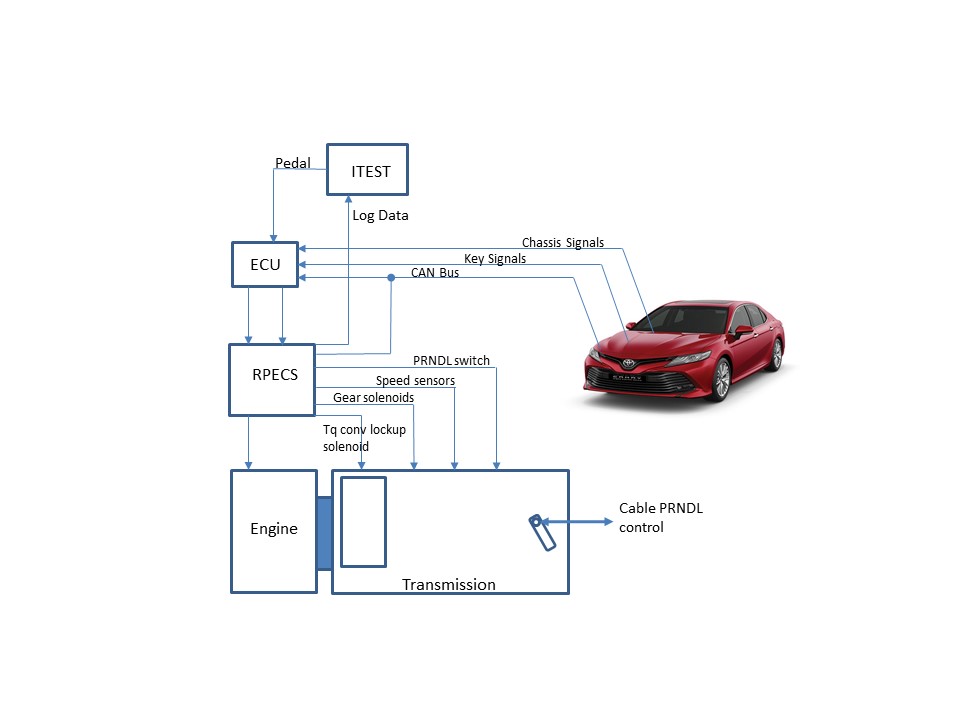
# Quality Procedures

This test program is covered by the Light-Duty Greenhouse Gas Test Program: Evaluating Potential Future Vehicle Technologies Quality Assurance Project Plan (QAPP).

# Test Methodology

**Description of Tethered Wiring Harness**

In modern vehicles, the engine control unit (ECU) is no longer the main computer. The ECU also requires communication with the body control module (BCM), the transmission control unit (TCU) and other various modules to monitor the entire vehicle operation (security, entry, key on, dash board signals, etc.). Because the ECU needs signals from these other modules to operate as calibrated by the manufacturer, the signals need to be extended to the test cell. The wiring harnesses connecting the ECU to the rest of the vehicle were lengthened to allow the engine and transmission in the dynamometer cell to be tethered to the vehicle chassis located outside the cell. Figure 1 illustrates the tethered wiring harness. Signal wires from the ECU to the engine and transmission were tapped to allow the signals to be either monitored or replaced as needed. This ensured testing could be performed without setting ECU/TCU fault codes and in a manner consistent with expected transmission operation in the vehicle.



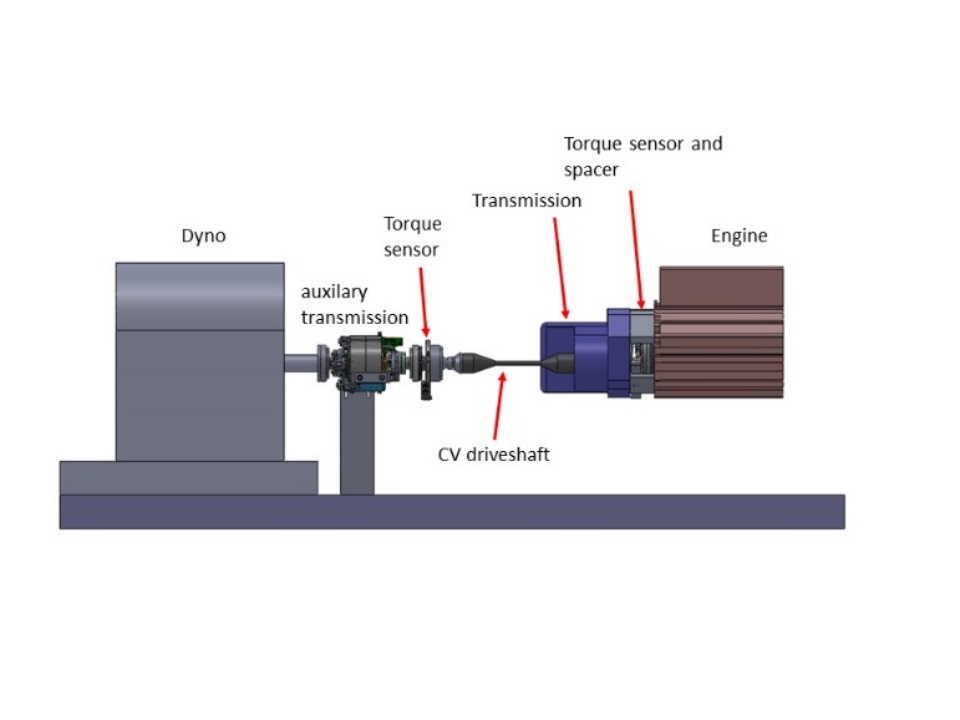
**Figure 1. Vehicle, Engine and Transmission Tethered Wire Harness**

# Engine Systems

A production Toyota Camry 2.5L A25A-FKS engine was used to support this transmission testing. Specific details for the engine setup and testing are described in SAE paper *SAE 2019-01-0249 Benchmarking a 2018 Toyota Camry 2.5-Liter Atkinson Cycle Engine with Cooled-EGR.pdf*. [2] The chassis throttle pedal inputs were used to control engine torque during testing by duplicating the production vehicle throttle pedal signals and controlling them with the iTest dyno control.

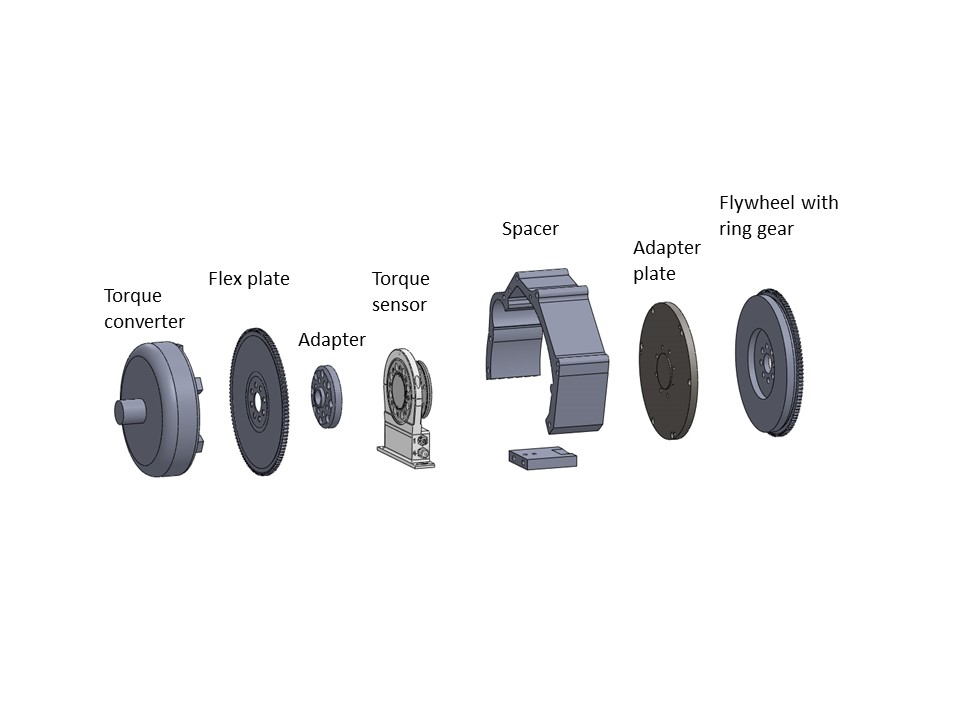
# Transmission Setup

To incorporate the transmission into the test cell, a system was designed to instrument and record the output speed and torque from both the engine and transmission. Figure 2 shows a model of the engine and transmission setup connection used in the test cell.

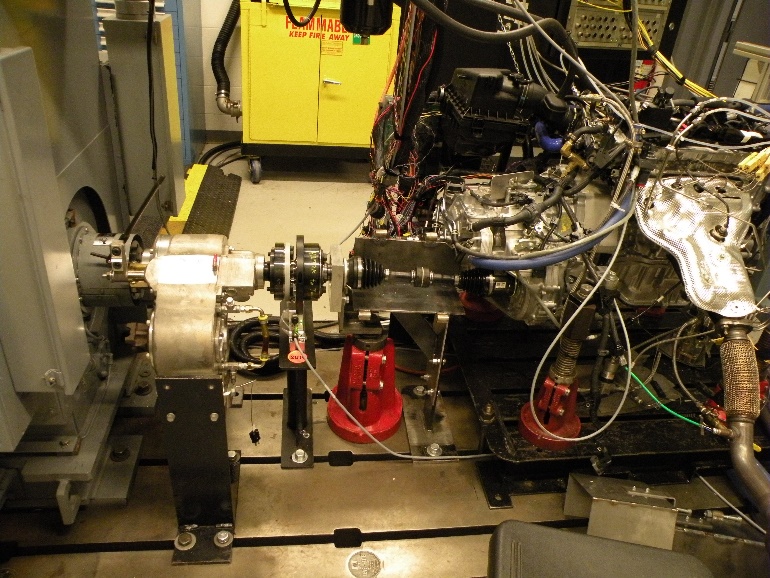


**Figure 2: Model of Engine and Transmission Testing Schematic**

As a part of the setup, a transmission input inline torque sensor was installed between the engine and transmission. This sensor needed to be placed in a way which maintained the concentricity and axial spacing of the transmission torque converter and engine flywheel. For this purpose, a custom flywheel was designed and built, incorporating the stock ring gear which allowed the engine to be started with the stock starter. Adapters were fabricated to connect the inline torque sensor to the engine flywheel and transmission flex-plate. The final design of this assembly is illustrated with an exploded view in Figure 3. Figure 4 shows the actual engine and transmission assembly, along with the torque sensors, after installation into the test cell.



**Figure 3: Transmission Inline Torque Sensor and Spacers Assembly**



**Figure 4: Final Engine and Transmission Test Cell Installation**

# Transmission Systems

Some key aspects of this streamlined transmission testing process are shifting/gear selection, fluid temperature control, engine start, and integration of an inline torque sensor. To properly control the transmission and record the appropriate data, a series of modifications and procedural steps were required as described below.

1. PRNDL Shift Controls: The transmission shifting is controlled by the PRNDL shift lever, normally mounted in the vehicle. For the test cell setup, a second PRNDL lever was mounted in the test cell and tethered to the iTest console. This PRNDL was used in manual mode to select and hold the transmission in a specific gear.
2. Transmission Fluid Cooling: The transmission fluid cooling circuit was kept in the stock configuration, which consisted of an external liquid-to-liquid cooler with transmission fluid and engine coolant flowing through it. This configuration allowed the engine coolant to both heat and cool the transmission fluid to maintain a constant temperature.
3. Transmission Gear Solenoids: To hold the transmission in a specific gear, the transmission gear solenoids were controlled directly by the RPECS, which emulated the stock control signals.
4. Torque Converter Clutch Lockup: The torque converter clutch is normally controlled by the transmission control unit (TCU). For this testing, the torque converter clutch was controlled directly by tapping into the wires connecting the clutch solenoid and the TCU. The signal coming out of the TCU was read by RPECS and a new signal was passed to the clutch solenoid that would allow either a locked or an unlocked clutch position as desired.
5. Auxiliary Transmission: The transmission was tested as a complete unit, including the differential gear assembly. With the differential in place, the transmission output torque is much higher than the test cell dynamometer can absorb, so an auxiliary transmission was installed between the transmission under test and the dynamometer. The auxiliary transmission had a 3.8:1 ratio to transform the speed and torque to a range that the dynamometer could absorb (see Figure 2).
6. Driveshaft: The test transmission was connected to the auxiliary transmission with the stock CV shaft (see Figure 2). The transmission differential was modified to lock the spider gears, so a single output shaft could be used.

# Data Set Definition

The data set logged for this testing included transmission parameters such as transmission oil pressure and temperature, input and output speed and torque, gear selection, and epid CAN data along with various engine parameters. The data were recorded by the iTest data acquisition system and logged into output files for all modes of testing. The data sets containing the transmission mapping test parameters are provided in the files:

* *4a- 2018 Toyota UB80E Transmission - Efficiency Test Data.xlsx*
* *4b- 2018 Toyota UB80E Transmission - Idle Speed Test Data.xlsx*
* *4c- 2018 Toyota UB80E Transmission – Torque Converter Stall Test Data.xlsx*
* *4d- 2018 Toyota UB80E Transmission – Coastdown Test Data.xlsx*
* *4e- 2018 Toyota UB80E Transmission – Temperature Test Data*

# Data Collection Procedure

The data were logged in steady state and transient modes according to the test requirements. The steady state mode consists of holding the speed and load fixed until stable and then logging the data at a 10 hz sampling rate for 10 seconds. The transient mode consists of continuous logging while sweeping speed or load and then logging at 10 hz for the appropriate number of seconds.

**Transmission Testing Procedure**

A series of tests were performed to determine the losses and operational characteristics of the transmission which included measuring total efficiency in each gear at a constant temperature, estimating the effect of temperature on torque losses, torque converter K-factor, required idle torque and transmission coastdown losses.

Transmission Torque Loss / Efficiency Testing

The transmission gearbox efficiency test was performed after the transmission was heated to a constant temperature between 85 ºC and 90 ºC. While at temperature, the transmission was held in a selected gear and the torque converter was locked up. The transmission input speed and load were controlled to a fixed value, and the speed and load of both the transmission input shaft and output shaft were logged at a 10 Hz sampling frequency for 10 seconds.

Idle Torque Testing

The engine torque required at idle to overcome transmission drag was also tested. This test was conducted by idling the engine, holding the transmission output speed to zero, unlocking the torque converter, and placing the transmission either in drive or in neutral. The transmission temperature was held constant at 85 ºC.

Torque Converter Stall Speed / K Factor Testing

A stall speed test was conducted by holding the transmission in a selected gear (sixth), with the torque converter unlocked and the transmission output speed held to zero. The transmission temperature was held constant near 90 ºC. The pedal input signal to the engine was increased, increasing both engine speed and load, until the maximum signal was reached. At this point, the engine speed (the “stall speed”) and shaft load were recorded.

Coastdown Testing

Finally, testing was performed to measure the transmission output losses in neutral, so the contribution of the transmission to vehicle losses during a coastdown could be determined. For this testing, the engine was operated at idle and the transmission was commanded to neutral. The transmission was warmed up to 85 ºC, then the dynamometer was set to 800 rpm. For testing, the dynamometer speed was decreased to 100 rpm over a 180-second timespan. Transmission output shaft torque and speed data were collected at a continuous rate.

Effect of Temperature on Transmission Torque Loss

To determine the effect of transmission fluid temperature changes on transmission torque loss, the transmission was operated at a constant speed, load, and gear over a period of time. Testing began at room temperature, and the transmission was warmed up; temperature, speed, and torque data were continuously recorded until a temperature of 90 ºC was reached. The transmission was allowed to cool overnight and the test process was repeated using a total of three different transmission gears.

# Data Set Processing

The iTest data collection system logs each single mode at 10 hz for 10 seconds and the data is subsequently averaged and written to the data file. The variable list also includes statistical information for selected variables such as standard deviation, coefficient of variation, minimum & maximum.

# Data Processing

|  |  |
| --- | --- |
| From the collected speed and load of both the transmission input shaft and output shaft, the input torque loss was calculated according to the following equation: | |
|  | Speed In = Transmission input shaft speed (rev/minute) |

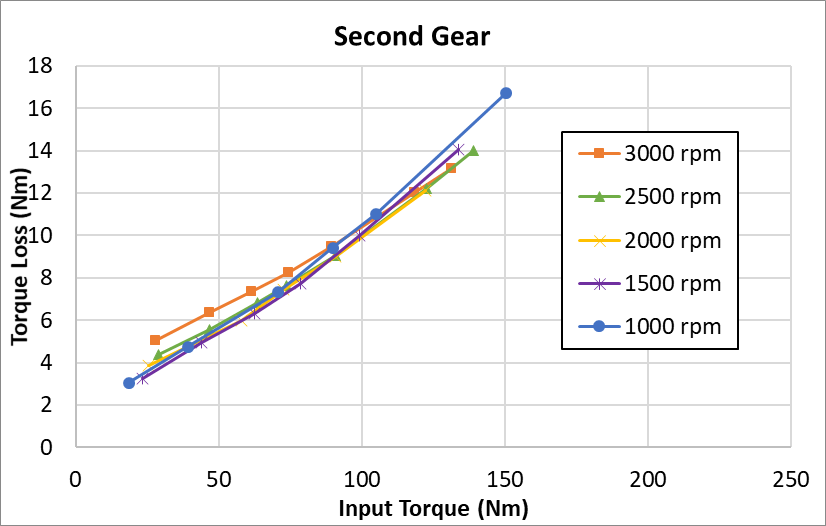
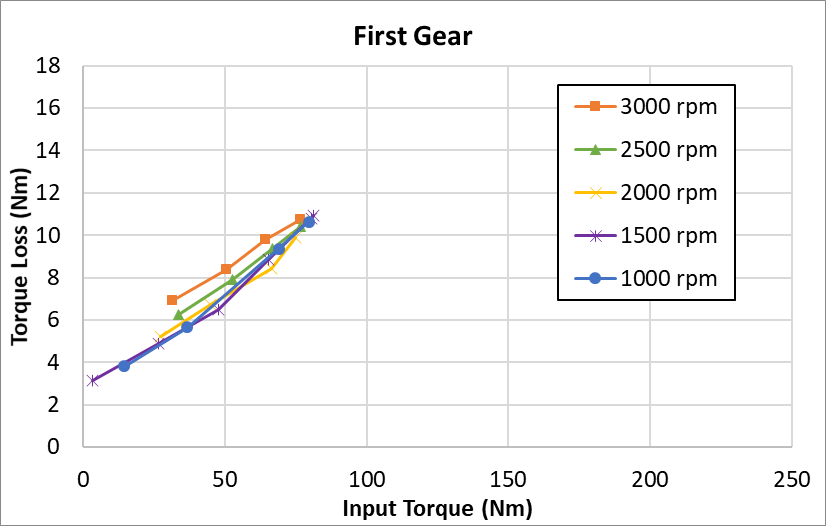
Torque converter K Factor was calculated according to the equation below using the measured values recorded from iTest.

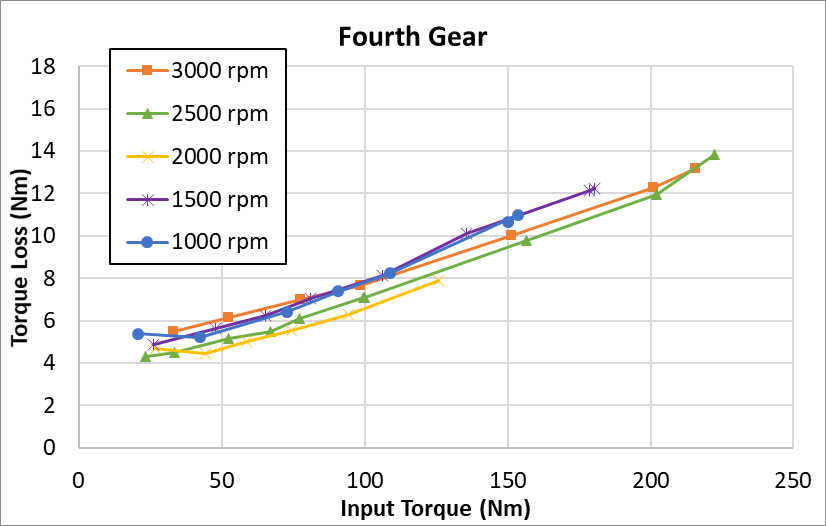
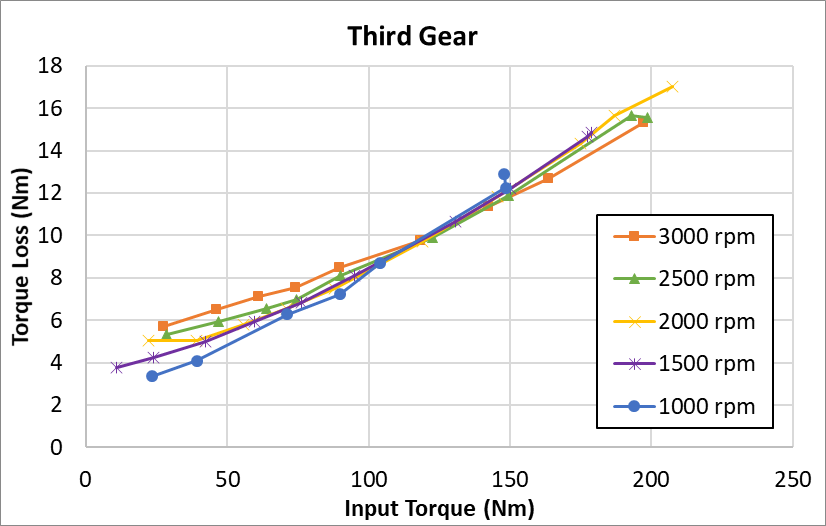
# Data Quality Control

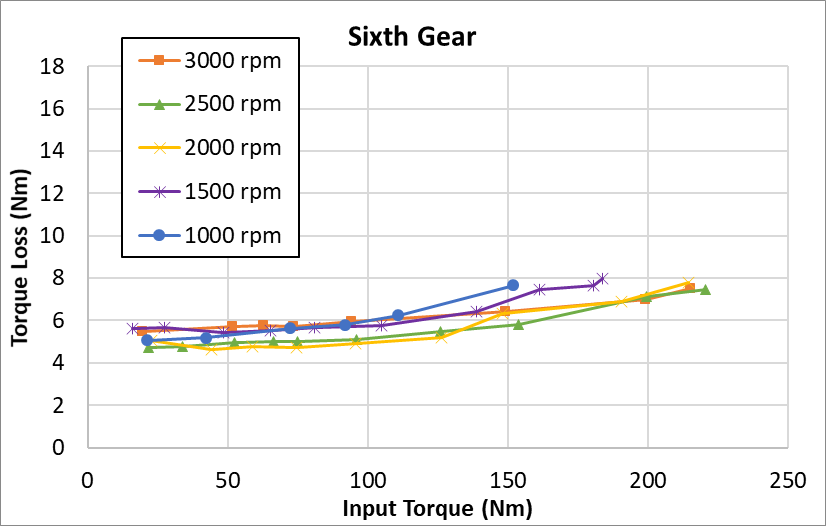
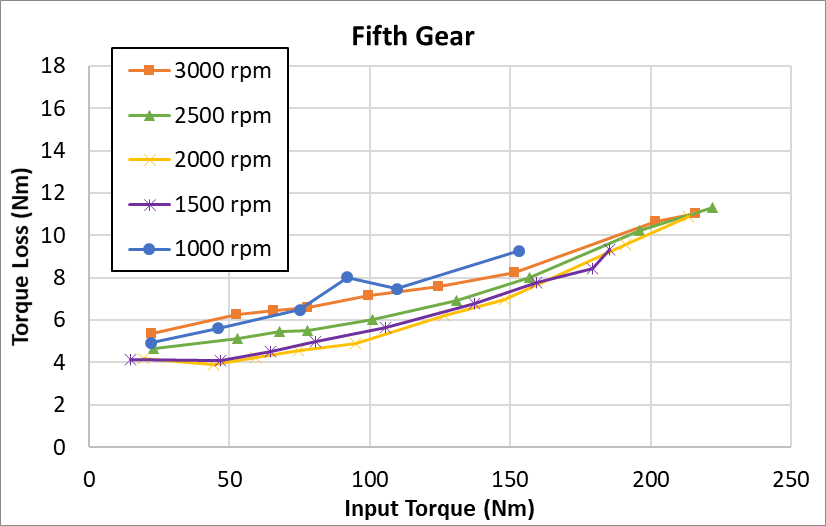
A core test data set is extracted from the iTest data logger file and includes test parameters selected to provide valuable information when evaluating transmission performance. Descriptions for the test parameter list are provided in the core test data set for reference. The core data set is analyzed for outlier data based on the statistical data included in the iTest data logger file. During these reviews, any outliers may be removed as needed based upon the discretion of the internal review team.

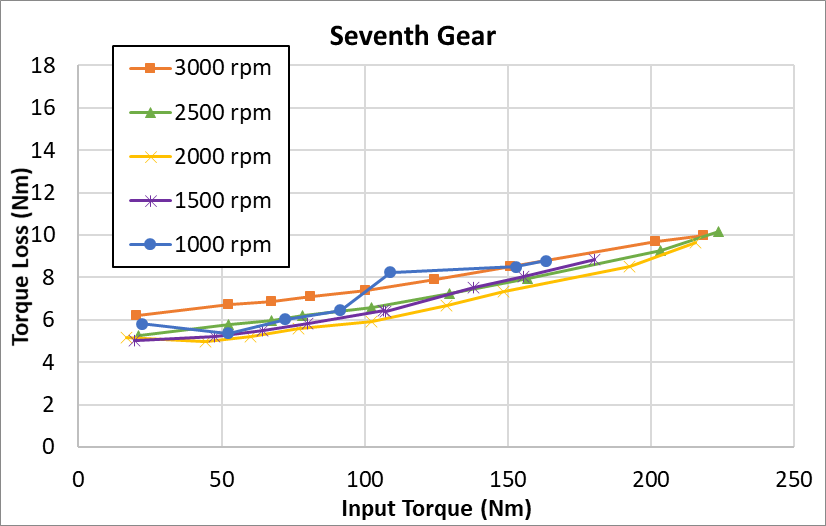
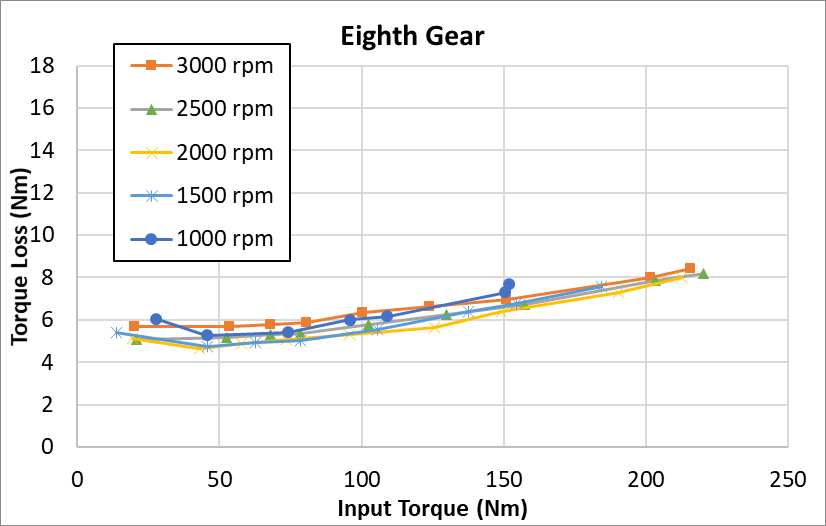
# Results

The final data sets containing the transmission mapping test parameters are provided in the data set files described above. The transmission efficiency, reported in percentage, for each individual gear as measured at various rpms is shown in Figure 5 below. Each gear was tested over a range of transmission speeds and loads. The data collected, for gears one through eight, are included in the file *4a- 2018 Toyota UB80E Transmission - Efficiency Test Data.xlsx*.









**Figure 5: UB80E Torque Loss Data, All Gears**

Idle Torque Testing

The engine idle torque measurements are included in the file *4b- 2018 Toyota UB80E Transmission - Idle Speed Test Data.xlsx*, and the speed and torque results are shown in Table 5.

**Table 5: Idle Torque Test Data**

|  |  |  |
| --- | --- | --- |
| **Condition** | **Engine Speed** | **Engine Torque** |
| Drive | 601 rpm | 15.8 Nm |
| Neutral | 654 rpm | 2.1 Nm |

Torque Converter Stall Speed / K Factor Testing

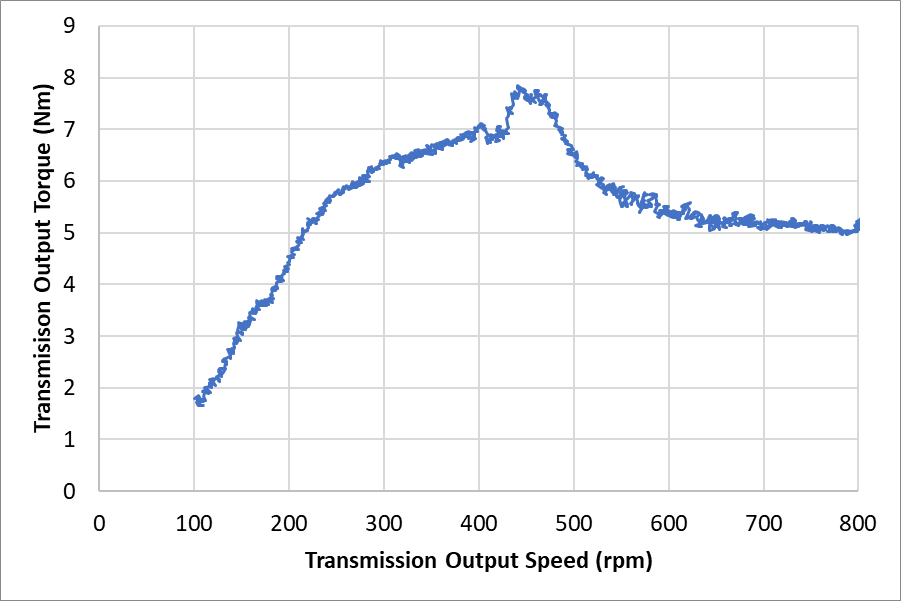
The recorded data were used to determine the K factor, a semi-dimensionless parameter commonly used in industry to compare torque converters with the same diameter and fluid properties. Two tests were completed, with the resulting measurements included in the file *4c- 2018 Toyota UB80E Transmission – Torque Converter Stall Test Data.xlsx* and the results of the K factor calculation are shown below in Table 6.

**Table 6: Torque Converter Stall Test Data**

|  |  |  |  |
| --- | --- | --- | --- |
| **Test** | **Stall Speed** | **Input Torque** | **K factor** |
| 1 | 2639 rpm | 203.3 Nm | 185.1 rpm/√Nm |
| 2 | 2622 rpm | 201.0 Nm | 184.9 rpm/√Nm |

Coastdown Testing

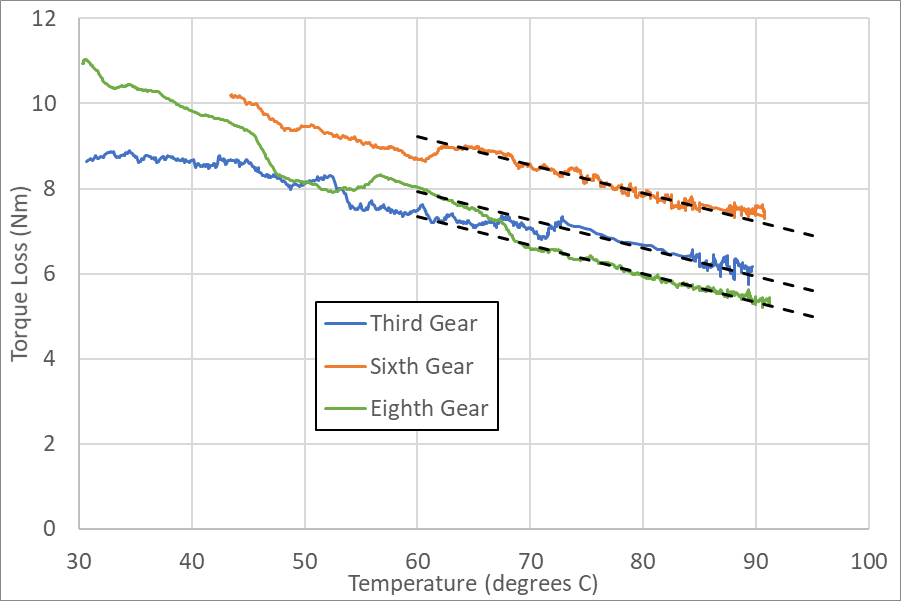
The data taken for the coastdown testing are recorded in the file *4d- 2018 Toyota UB80E Transmission – Coastdown Test Data.xlsx*. An example result is shown in Figure 6.



**Figure 6: UB80E Transmission Coastdown Drag**

Effect of Temperature on Transmission Torque Loss

Finally, the data collected for the temperature effect are included in the file *4e- 2018 Toyota UB80E Transmission – Temperature Test Data*. These data generally exhibit a torque loss reduction of about one Newton per 15 ºC temperature increase, over the range of 70 ºC to 90 ºC as shown by the dashed lines in Figure 7.



**Figure 7: UB80E Torque Losses as a Function of Temperature**

# Uncertainty

General Uncertainty Notes

The dynamometer data were collected according to best engineering procedures and any uncertainty or test-to-test variation is controlled by adhering to the laboratory’s standard operating procedures documented in accordance with NVFEL’s ISO 17025 accredited quality system.

The supporting data sets include discrete sensor signals and CAN data which are reported as recorded from the test cell but have not been calibrated, checked, adjusted, or analyzed. This reported data may be valuable to use as reference parameters but should, in general, be considered reference only. Users should exercise good engineering judgement when determining the extent to which they wish to rely on these reported values for any analysis purpose.

Sensor/Signal Uncertainties

The uncertainties of the signals [u(signal)] in the data set can be based on (a) the uncertainty associated with the calibration standard, (b) the uncertainty of the sensor calibration [u(calibration)], and (c) the uncertainty of the signal during operation [u(operation)]. The uncertainty associated with the calibration standard is assumed to be negligible when compared to other uncertainties and thus this uncertainty is not considered for this calculation.

To determine the uncertainty of the sensor calibration (b), past calibration records were assessed and the difference between the standard and measured quantities were used to calculate uncertainty. The “speed in” signal was measured by a 3600-pulse per revolution shaft encoder which was not calibrated; thus, the calibration uncertainty was estimated for this sensor based on the pulse count.

To determine the uncertainty of the signal during operation (c), the standard deviations for each signal were calculated from the testing data and the average was used to calculate the variance of the mean, and thus the uncertainty,

Where n is the number of data points in a mode (100 in this case, with 10-second modes of 10 Hz recording frequency). The standard uncertainty for each signal is given in Table 7. The operational and signal uncertainties given represent an average across a range of points, and are given as a reference only.

**Table 7: Standard Uncertainties for Signals**

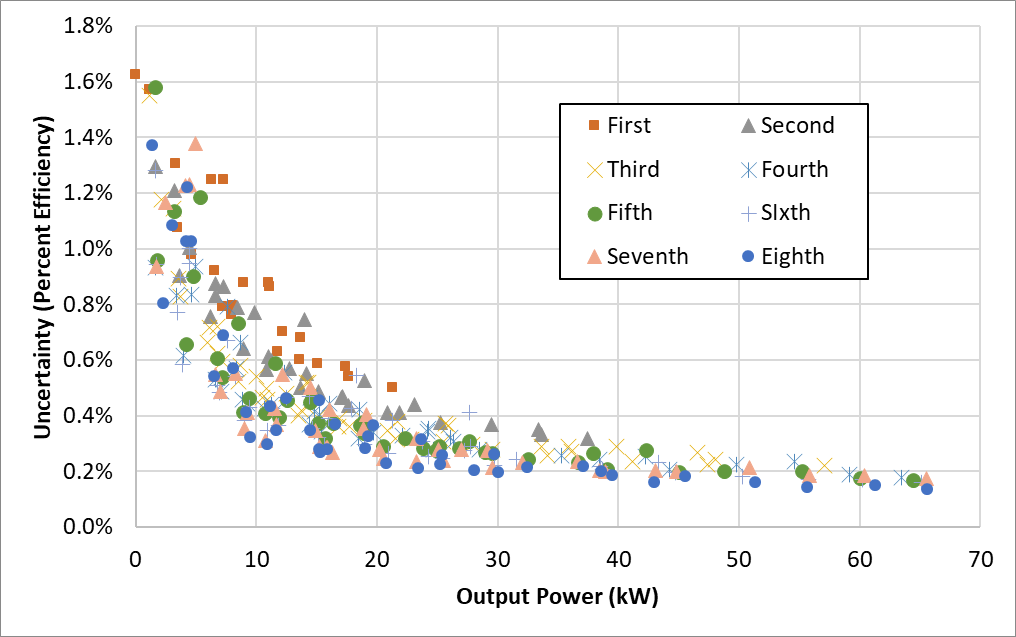
|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Signal | Symbol | u(calibration) | u(operation) (ref) | u(signal) (ref) |
| Speed In (rpm) | *ωi* | 0.656 | 0.334 | 0.736 |
| Torque In (Nm) | *Ti* | 0.230 | 0.127 | 0.263 |
| Speed Out (rpm) | *ωo* | 0.961 | 0.230 | 0.988 |
| Torque Out (Nm) | *To* | 0.230 | 0.285 | 0.366 |

Uncertainty of Transmission Efficiency

The transmission efficiency is the ratio of the output power (speed\*torque) to the input power. The total uncertainty for transmission efficiency is calculated by:

or

Standard uncertainties are analogous to standard deviations, such that it would be expected that, for a given set of data, the “true” value of a parameter would fall within +/-1*uc* for 68% of the data points, the “true” value of a parameter would fall within +/-2*uc* for 95% of the data points, and the “true” value of a parameter would fall within +/-3*uc* for 99.7% of the data points. Calculated uncertainty of the transmission efficiency for all data points with output power greater than zero is reported in Figure 8.



**Figure 8. Uncertainty of Efficiency Measurement**

As a check on the uncertainty calculation, points within the data set that had near-duplicate output speed and torque were compared. Nine pairs of data points were analyzed; of these, the largest differential was slightly over one expected standard uncertainty, indicating that the uncertainty calculation is likely reasonably representative of actual uncertainties in the data.

# Discussion and Data Usage

The intent of this testing was to characterize the performance of a 2018 Toyota UB80E eight-speed automatic transmission. The method of benchmarking a transmission coupled to an engine has been demonstrated and is best implemented when performed in conjunction with an engine benchmarking test. This method of adding the transmission to the engine dyno setup to include inline torque measurements is straightforward and does not add significantly to the test cell complexity. The overall project is described in more detail in the SAE paper *SAE 2020-01-1286.pdf (“Benchmarking a 2018 Toyota Camry UB80E Eight-Speed Automatic Transmission”*). [1] Additional details on the engine testing portion of this transmission testing are provided in SAE paper *SAE 2019-01-0249.pdf (“Benchmarking a 2018 Toyota Camry 2.5-Liter Atkinson Cycle Engine with Cooled-EGR”)*[2] and NCAT’s test packages *2018 Toyota 2.5L A25A-FKS Engine Tier 2 Fuel – Test Data Package and 2018 Toyota 2.5L A25A-FKS Engine Tier 3 Fuel – Test Data Package*.

This streamlined benchmarking method for a transmission is lower cost and less complex than an independent transmission component benchmarking test. In addition, the tethered methodology ensures that engine and transmission are controlled in tandem according to the manufacturer’s calibrations. However, the data set for this method is limited by the dynamometer’s ability to absorb torque, especially in the lower gear ranges.

The transmission data collected using this benchmarking were supplied as inputs to the ALPHA model including transmission gear efficiency, torque converter K factors, and spin losses. Considering the limitations on the available test data from this pilot project, the ALPHA simulation results showed a very good match to the test data providing confidence in this streamlined transmission benchmarking method.

# 

# References

[1] Moskalik, A., Stuhldreher, M., and Kargul, J., “*Benchmarking a 2018 Toyota Camry UB80E Eight-Speed Automatic Transmission*,” SAE Technical Paper 2020-01-1286, 2020, doi:10.4271/2020-01-1286.

[2] Kargul, J., Stuhldreher, M., Barba, D., Schenk, C. et al., “*Benchmarking a 2018 Toyota Camry 2.5-Liter Atkinson Cycle Engine with Cooled-EGR*,” SAE Technical Paper 2019-01-0249, 2019, doi:10.4271/2019-01-0249.