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Heavy-Duty Vehicle Transmission Benchmarking – Volvo I-Shift 12-Speed Automated Manual Transmission

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16. Abstract

The objective of this project was to evaluate and characterize the Volvo I-Shift 12-speed AMT (automated manual transmission) available for use in heavy-duty vehicles produced for the North American market. The evaluation of this transmission consisted of in-gear efficiency mapping, torque converter mapping, torque converter engagement strategy characterization, oil pump testing, parasitic loss determination, shift schedule identification with laden versus unladen shift algorithm mapping, characterization of ratio spread, and packaging envelope. The transmission benchmarking efforts undertaken as part of this project sought to provide NHTSA with powertrain data that improves vehicle modeling and standard writing activities. This report details the technological advancements of the I-Shift transmission and the empirical data collected as part of the project.

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List of Acronyms

AMT	automated manual transmission
DAQ	data acquisition system
SwRI	Southwest Research Institute

Foreword

The objective of this project was to evaluate and characterize different transmission architectures currently available in North American heavy-duty vehicles. The National Highway Traffic Safety Administration task order includes the reverse engineering of advanced transmissions offered in MY2019 or newer vehicles produced for the North American market. The Southwest Research Institute has worked with NHTSA and project partners to provide NHTSA with empirical data collection, technical support, and data analysis on the transmissions identified for benchmarking consideration. Evaluation of the benchmarked transmission consisted of component efficiency mapping, torque converter mapping and engagement strategy, oil pump testing, parasitic loss determination, shift schedule identification, as well as laden and unladen shift algorithm mapping. General ratio spread and packaging envelope of each transmission has also been documented while completing the task order. Throughout the duration of the project, attention has been paid to identify individual components of the transmissions that advance fuel economy and quantify their benefit.

This report follows the specific requirements or SRs outlined by the original NHTSA task order. Each SR section addresses unique objectives of the overall project. For the Volvo I-Shift NHTSA requested efficiency testing only and did not want the teardown and costing analysis performed.

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Project Introduction

The objective of this project was to evaluate and characterize the Volvo I-Shift 12-speed AMT (automated manual transmission) available for use in heavy-duty vehicles produced for the North American market. The evaluation of this transmission consisted of in-gear efficiency mapping, torque converter mapping, torque converter engagement strategy characterization, oil pump testing, parasitic loss determination, shift schedule identification with laden versus unladen shift algorithm mapping, characterization of ratio spread, and packaging envelope.

The transmission benchmarking efforts undertaken as part of this project sought to provide NHTSA with powertrain data that improves vehicle modeling and standard writing activities. This report details the technological advancements of the I-Shift transmission and the empirical data collected as part of the project.

Introduction to Volvo I-Shift AT2612F

The Volvo I-Shift was first released in 2001 and has maintained status as an industry leader since its introduction to the Class 8 market. The I-Shift features automated clutch and shifting events with a wide ratio spread for peak fuel efficiency. The AT2612F tested as part of the FY2021 project year is an AMT that features 12 forward gears and 4 reverse gears in its standard form. The gear shifting and clutch operation is controlled pneumatically via solenoids that act on four shift forks to net each gear state. The I-Shift is available in Volvo and Mack branded trucks, and accounts for the large majority, approximately 93 percent in 2019, of transmissions sold in the Volvo group's trucks.

Areas of Efficiency Improvement

Class 8 two-pedal transmissions consist of conventional automatics and AMTs. Both automatics and AMTs are cited as reducing driver fatigue. AMTs also tout improved fleet fuel economy, normalized service intervals across the fleet, and reduced driver-to-driver variation in vehicle operation. The Volvo I-Shift gear train mirrors that of a manual transmission with helical reduction gear sets and a planetary overdrive. The efficiency improvements of the AMT are derived from engine and transmission calibration integration and reduced torque interrupts during shifts. Continued efficiency and shift performance improvements are derived from greater powertrain and chassis connectivity throughout the vehicle. The continuous feedback of vehicle grade, speed, and weight alongside the powertrain parameters helps to better inform the AMT gear holding and predictive logic controls. The Volvo VNR truck tested included rear ride height sensors that in combination with air suspension pressure is used to calculate vehicle weight and load. The Volvo's I-See system further extends the vehicle integration and I-Shift optimization through the intelligent cruise system. The intelligent cruise vision system maximizes fuel economy by learning and managing road topology. The system uses the I-Shift transmission to hold gear near the crest of a hill and to disconnect the engine and transmission for low parasitic loss coasting.

Transmission Features

The I-Shift features an internal oil pump, filter, and optional external oil cooler for applications with greater heat rejection requirements. The I-Shift is available in several configurations that provide extra forward or reverse gears depending on specific driving needs of a customer. The I-Shift is available with vocational specific gearing and power take-off outputs suitable for the refuse, gravel, or paving markets. The transmission features software to allow for different driving modes including economy, performance, and a manual gear control mode to meet operator needs. The Volvo-specified transmission fluid for the I-Shift also features a 500,000-mile service interval to help lower operational costs.

SR-2 Deliverables – Gear Efficiency Maps

Gear Efficiency Mapping – Volvo I-Shift

Component Level Testing Setup

The Volvo I-Shift component testing was performed in a SwRI drivetrain test cell in accordance with the procedures set forth in Transmission Efficiency Test, 40 CFR 1037.565 for transmission efficiency testing and SwRI processes. A remanufactured Volvo I-Shift AT2612F transmission was acquired, and a break-in process was performed using appropriate engineering judgement for adequate stabilization.

The AT2612F transmission features 12 forward gears and 4 reverse gears controlled by 4 shift forks. Shifting in the vehicle is performed using the vehicle air supply with shift solenoids that direct air onto either side of the target piston that controls the shift fork. SwRI manually controlled the shifting during the component testing by applying air to achieve the required gear state. The table used to determine the correct shift fork position for each gear, and map of air supply port locations, are shown in Table 1. A portion of the shift fork assembly that doesn't include the high and low range fork is shown in Figure 1 along with a photo of the corresponding shift fork pocket and gears.

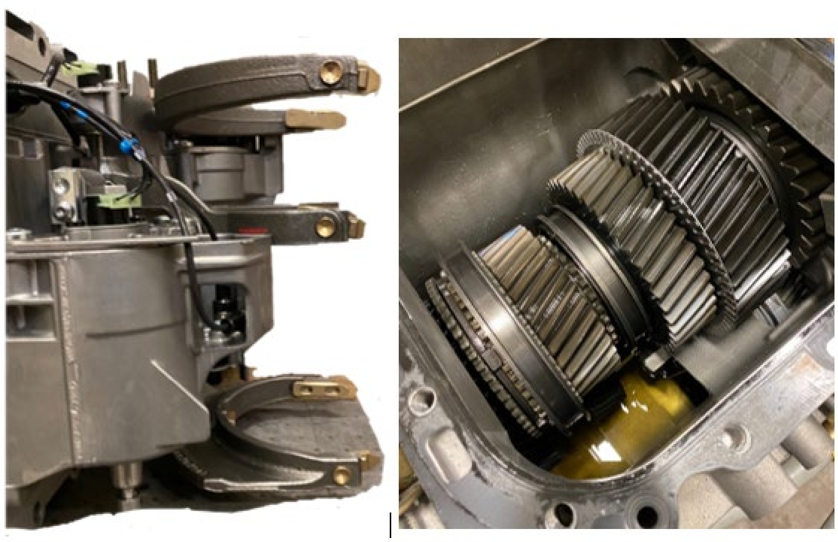
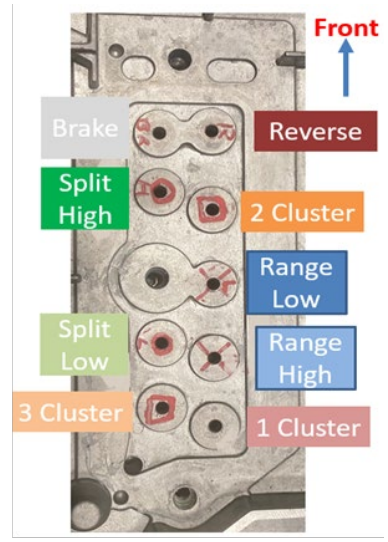


Figure 1. Volvo I-Shift shift fork assembly and gearing

Table 1. Volvo I-Shift shift fork mapping by gear and air supply port locations

Gear	Ratio	1/Rev Cluster	2/3 Cluster	Split	Range
1	14.94	1	Neutral	Low	Low
2	11.73	1	Neutral	High	Low
3	9.04	Neutral	2	Low	Low
4	7.09	Neutral	2	High	Low
5	5.54	Neutral	3	Low	Low
6	4.35	Neutral	3	High	Low
7	3.44	1	Neutral	Low	High
8	2.7	1	Neutral	High	High
9	2.08	Neutral	2	Low	High
10	1.63	Neutral	2	High	High
11	1.27	Neutral	3	Low	High
12	1	Neutral	3	High	High



The transmission was connected to a SwRI headstand with the clutch removed. To create the input driver, SwRI harvested the splined portion of the clutch that connected to the input shaft of the transmission and fixed the component to a driver attached to the HBM inline torque meter.[1] The arrangement is shown in Figure 2.

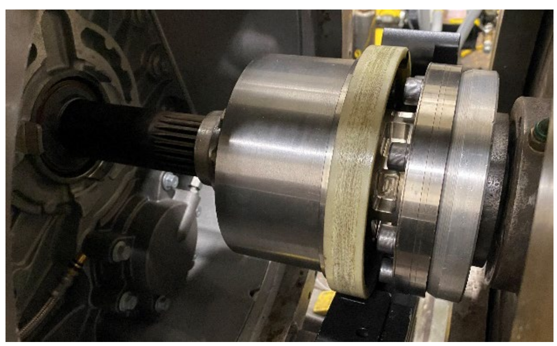


Figure 2. Volvo I-Shift input driver and input torque meter

The transmission's output connected directly to an output shaft that also incorporated an inline torque meter. Fluid conditioning was performed by drawing fluid out of the transmission's sump and returning it via an external pump controlling to the required temperature of 80°C ± 3°C for all testing. The temperature requirement was chosen based on instruction from Transmission Efficiency Test, 40 CFR 1037.565 for transmissions without a torque converter. Figure 3 shows the I-Shift transmission as installed on the test stand.

[1] Hottinger Brüel & Kjær, Virum, Denmark. www.hbm.com/en/0264/torque-transducers-torque-sensors-torque-meters

Figure 3. Volvo I-Shift transmission installed on the test stand

General information about the specific Volvo I-Shift transmission tested is shown in Table 2 and Figure 4.

Table 2. I-Shift transmission general information

Transmission designation	AT 2612F
Maximum input torque	2,600 Nm
Weight without oil	278 kg
Oil capacity	Approximately 16.1 liters
Number of forward gears	12
Number of reverse gears	4

Figure 4. Volvo I-Shift transmission identifying information

Instrumentation and Calibration

Input and output speed and torque measurement requirements were set by Work Input and Output Sensors, Shaft Work, 40 CFR 1065.210(b). Table 3 shows the requirements and details on the instrumentation used to complete each measurement.

Table 3. Torque meter and speed measurement details

Measurement	Requirement	Actual	Device
Speed	± 0.05%	0.03%	HBM T12 inline torque meter speed output
Loaded input torque	± 0.2% @ 1,500 Nm (highest loaded point)	0.03% over full scale	HBM T12 2 kNm inline torque meter
Unloaded input torque	± 0.1% @ 1,500 Nm (highest loaded point)	0.03% over full scale	HBM T12 2 kNm inline torque meter
Output torque	± 0.2% @ highest torque for each gear ratio	0.1% over full scale	HBM T10 5 kNm inline torque meter

HBM flange-type torque meters were used to measure input and output torque. Each torque meter was calibrated by a deadweight calibration. The torque meter rotor and antenna were mounted on a calibration stand with the appropriate mounting hub. A torque arm was placed on the load hanger in an incremental pattern until the target torque was applied. The torque calculated from the applied weight (F x d), and torque from the data acquisition system were recorded. The two zero-torque measurements from the DAQ were averaged to obtain the calibrated torque meter offset. The calibrated torque meter offset was then subtracted from each of the DAQ torque measurements to correct the DAQ channel offset for each torque measurement. The measurement errors at each applied load point were recorded to find the maximum meter measurement error value. This maximum error value was checked against the stated meter accuracy to ensure that the meter adheres to the accuracy and linearity requirements set forth by the manufacturer. The two torque meters used for testing had measurement errors within the tolerance for each meter.

Calibration of the speed channels was a tiered process. First, a frequency generator was used to calibrate the input and output speed readings in the DAQ by providing an ideal square wave of known frequencies. The frequency generator was calibrated and tracked through the SwRI calibration laboratory against proven standards. The DAQ speed channels were corrected for offset and linearity based on the error measured against the frequency calibrator, prior to testing. This corrected the gate/timing error characteristics of the DAQ frequency card. Speed measurement and speed control to setpoint were then verified for accurate reproduction according to Verifications for Accuracy, Repeatability, and Noise, 40 CFR 1065.305, and equation 1065.602-4.

Matrix Determinations

The test matrix boundaries were set based on guidance from the Transmission Efficiency Test, 40 CFR 1037.565 procedure, and within SwRI test stand equipment limitations. The test unit input speed targets were determined by selecting four equidistant points between idle (600 rpm) and maximum operational speed (2,100 rpm). SwRI tested to the maximum input torque that could be achieved within the test stand limitations for each gear, though typically well below the capability of the transmission. An example target matrix is shown in Table 4 for 5th gear.

During testing, each test point was taken three times for a duration of 30 seconds at 10 Hz. The three points were averaged for the final value reported.

Table 4. Example test matrix from the Volvo I-Shift test

Gear	**Ratio**	**Input Speed (rpm)**					
Fifth	5.54	600	900	1,200	1,500	1,800	2,100
Input Torque (Nm)	100						
	200						
	300						
	400						
	500						
	600						
	750						

Volvo I-Shift Test Results

Tabulated and graphical efficiency test results are shown in Appendix A. Figure 5 shows an example of the efficiency data from 6th gear on the I-Shift. All data points were within the required repeatability criteria in accordance with EPA regulation.[2]

[2] The EPA regulation is 40 C.F.R. 1037.565. Part 1037 is Control of Emissions From New Heavy-Duty Vehicles. § 1037.565 is "Transmission efficiency test." A sub-paragraph reads, "(iv) Note that GEM calculates power loss between tested or default values by linear interpolation, except that GEM may extrapolate outside of measured values to account for testing at torque setpoints below 75% as specified in paragraph (d)(2)(ii) of this section." GEM is the EPA's greenhouse gas emissions model; see *Greenhouse Gas Emissions Model (GEM) User Guide*, EPA publication no. EPA-420-B-10-039, dated October 2010 (https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1008V0N.TXT).

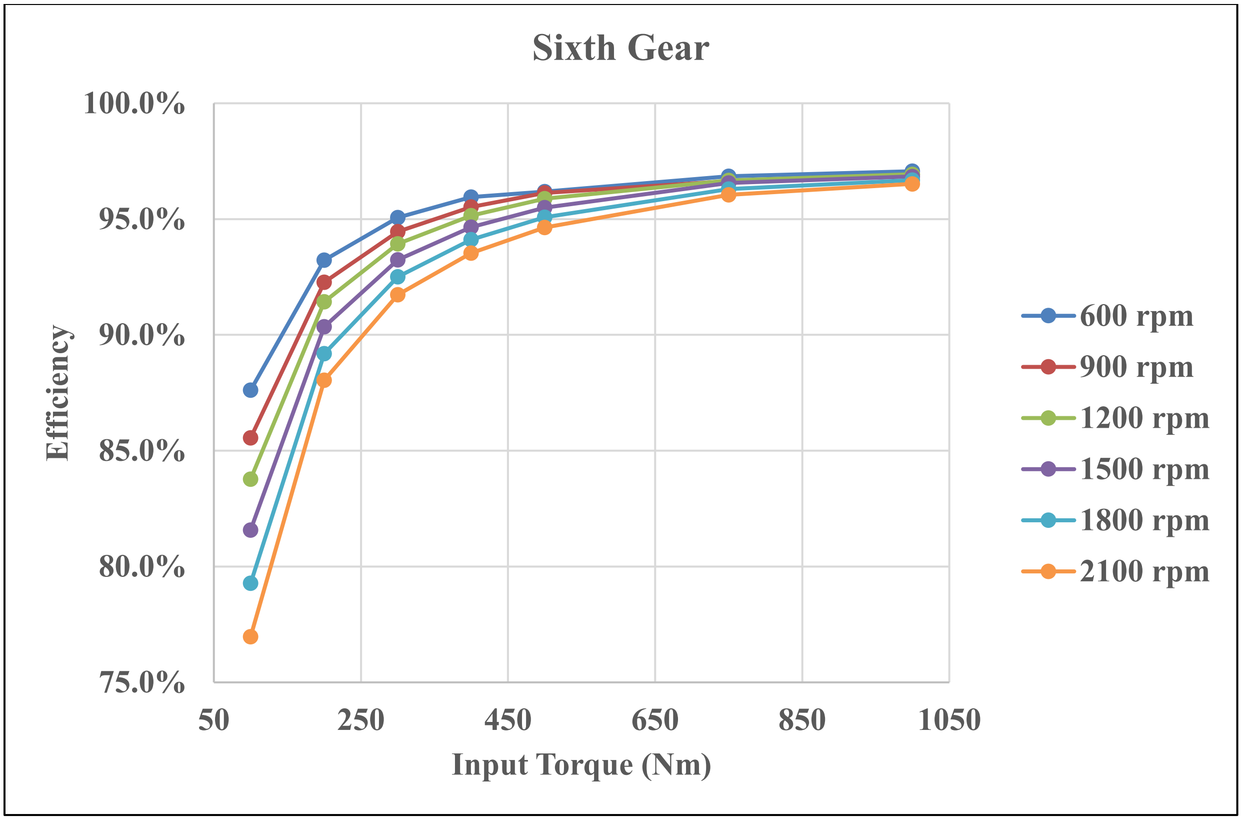


Figure 5. Volvo I-Shift sixth gear efficiency data

Transmission Inertia Mapping per Gear

Inertia Test Description

SwRI completes inertia testing by disconnecting the transmission output and measuring input torque over a controlled, constant acceleration rate speed sweep. The inertial component torque is calculated by subtracting out the measured parasitic loss torque at equivalent input speed conditions. Inertia measurement results and subsequent calculations are shown in Figure 6 and Table 5. Additional details about the inertia data are in Appendix B.

Inertia Test Results

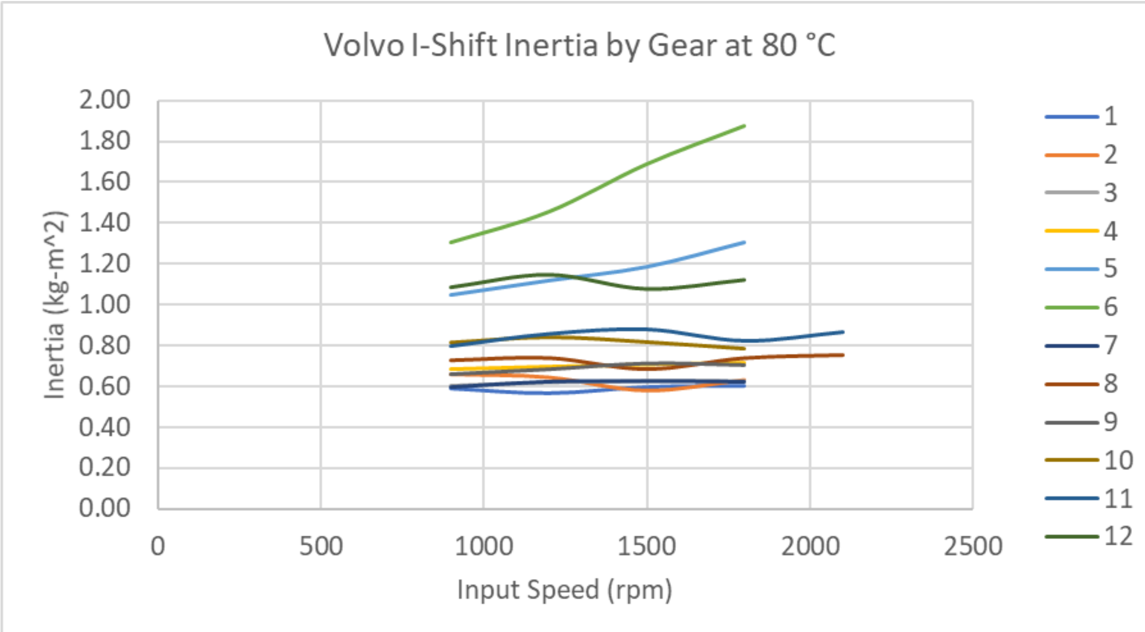


Figure 6. Volvo I-Shift inertia data

Table 5. Volvo I-Shift inertia test results

Inertia $(kg - m^2)$

Gear	Average	Gear	Average
1	0.62	7	0.65
2	0.73	8	0.75
3	0.64	9	0.72
4	0.73	10	0.89
5	1.17	11	0.85
6	1.54	12	1.11

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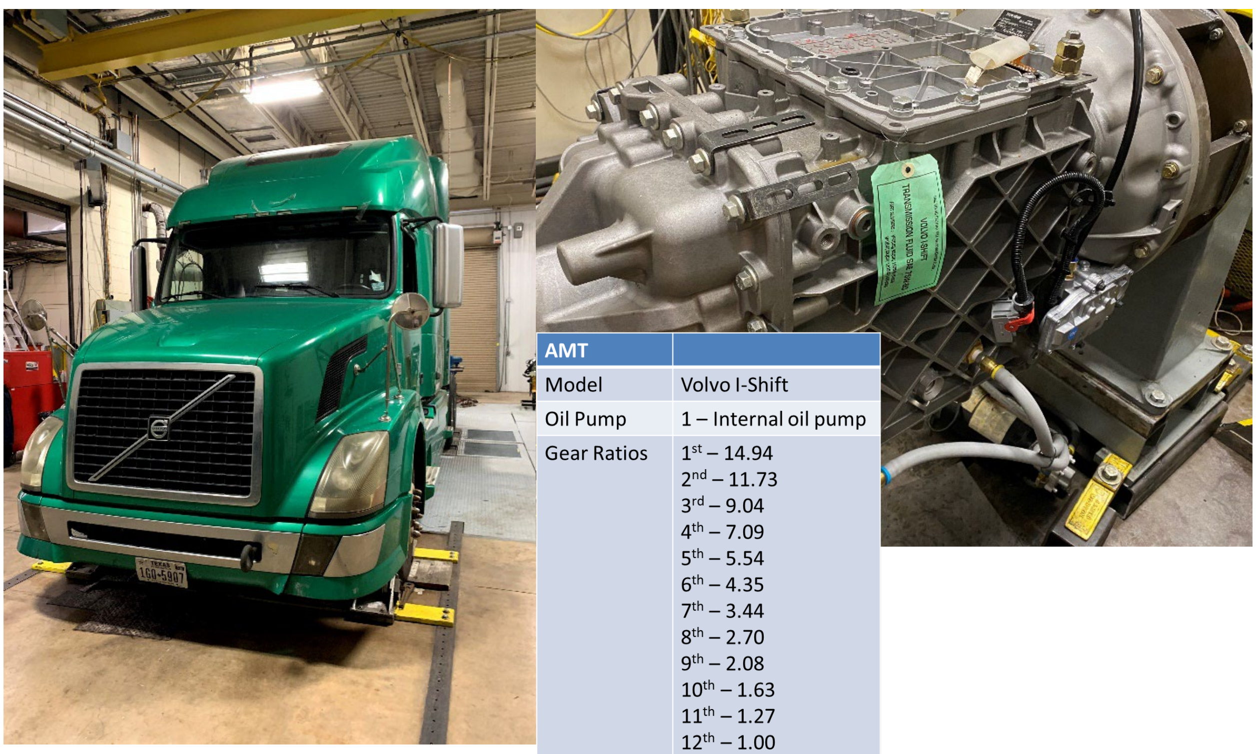
SR-3 Deliverables – Overall Transmission Characterization

The SR-3 task focused on overall transmission characterization for the chosen benchmark units. This task intended to provide additional information on each benchmark transmission to aid in comparisons between available technologies and highlight features of the benchmark transmissions that contribute to fuel efficiency.

Ratio Determination and Physical Packaging Dimensions

The I-Shift transmission offers several gear ratio configurations to suit specific customer use requirements. Figure 7 shows the I-Shift gear ratios as set up for the in-use testing on the Volvo VNR and bench testing. The I-Shift provides additional gear capability by placing a gear reduction module between the clutch housing and main gear housing of the transmission extending the overall length of the transmission. Table 6 shows the transmission gear configurations that can be ordered.

The I-Shift packages within the same frame as conventional automatics or manual transmissions in the same class of vehicle. The I-Shift features a standard SAE No. 1 bellhousing and pneumatic shifting and clutch control through a single air input location for simple integration into several vehicle configurations.



AMT	
Model	Volvo I-Shift
Oil Pump	1 – Internal oil pump
Gear Ratios	1st – 14.94 2nd – 11.73 3rd – 9.04 4th – 7.09 5th – 5.54 6th – 4.35 7th – 3.44 8th – 2.70 9th – 2.08 10th – 1.63 11th – 1.27 12th – 1.00

Figure 7. Test vehicle summary – Volvo VNR – I-Shift AMT

Table 6. Volvo I-Shift gear configurations

		AT2612F	AT2612F with Crawler	AT2612F with Ultra Low Crawler	AT2612F with Multi Speed Reverse and Ultra Low Crawler
	Gear	Ratio	Ratio	Ratio	Ratio
Forward	**C1**			32.04	32.04
	C2		19.38	19.38	19.38
	1	14.94	14.94	14.94	14.94
	2	11.73	11.73	11.73	11.73
	3	9.04	9.04	9.04	9.04
	4	7.09	7.09	7.09	7.09
	5	5.54	5.54	5.54	5.54
	6	4.35	4.35	4.35	4.35
	7	3.44	3.44	3.44	3.44
	8	2.7	2.7	2.7	2.7
	9	2.08	2.08	2.08	2.08
	10	1.63	1.63	1.63	1.63
	11	1.27	1.27	1.27	1.27
	12	1	1	1	1
Reverse	**RC**				37.49
	R1	17.48	17.48	17.48	17.48
	R2	13.73	13.73	13.73	13.73
	R3	4.02	4.02	4.02	8.62
	R4	3.16	3.16	3.16	4.02
	R5				3.16

Parasitic Loss Mapping

The parasitic loss mapping consisted of unloaded spin loss testing for the I-Shift transmission. This transmission evaluation characterized the speed-based losses of the transmission with no load applied. Input torque meters were sized and calibrated for additional fidelity during the spin loss testing. The output prop shaft was removed for longitudinal transmission testing.

Volvo I-Shift Parasitic Results

The parasitic loss testing on the I-Shift was performed following procedures detailed by Transmission Efficiency Test, 40 CFR 1037.565 for transmission efficiency testing. Testing was performed at a controlled sump temperature of 80°C ± 3°C. Loss data was taken at each input speed that was tested during the loaded efficiency testing for each gear. The entire matrix was completed three times sequentially, recording for 30 seconds at 10 Hz at each test point. The three points were then averaged for the final data points shown in Table 7.

The differences in loss torque between gears is easily characterized by certain clusters of gears being activated. The transmission shift pattern shown in Table 1 details the common gear sets that only differentiate by either high or low range shift fork. Gear pairs include 1st and 7th, 2nd and 8th, and on up to 6th and 12th. A common trend of output speed and input speed dependent losses are also shown in the data.

Table 7. Volvo I-Shift parasitic loss torque

	Parasitic Loss Torque by Gear (Nm)											
Input Speed (rpm)	1	2	3	4	5	6	7	8	9	10	11	12
600	3.7	4.8	4.2	5.6	3.7	4.9	3.9	5.0	4.4	5.7	5.4	7.0
900	4.9	6.6	5.5	7.2	4.9	6.6	5.1	6.7	5.6	7.4	6.9	9.2
1,200	6.0	7.8	6.5	8.7	6.1	7.9	6.2	8.0	6.7	8.9	8.2	11.0
1,500	6.8	9.2	7.6	10.3	7.0	9.1	7.0	9.3	7.7	10.5	9.5	13.0
1,800	7.7	10.5	8.5	11.8	7.8	10.5	8.0	10.7	8.7	12.0	10.7	15.0
2,100	8.5	11.9	9.5	13.5	8.8	12.1	8.8	12.3	9.8	13.6	11.8	17.1

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SR-4 Deliverables – In-Use Performance Testing

SR-4 deliverables were centered around establishing an understanding of transmission behavior in the vehicle. The following sections explain the methods used to complete the vehicle in-use testing with the goal of establishing a baseline of transmission operation and understanding the transmission control and shifting behavior.

Volvo VNR Vehicle Instrumentation

Data collected for the vehicle-level testing on the Volvo VNR with I-Shift was collected primarily from the vehicle on-board diagnostics, but with added feedback from the dyno rollers for an independent load and speed measurement. Main channels collected included vehicle speed, dyno roller force, current gear, accelerator pedal position percentage, and engine speed.

The accelerator pedal position was controlled by a physical actuator placed in-line with the accelerator pedal. Figure 8 shows the actuator in place for testing. Figure 9 shows the Volvo on SwRI’s heavy-duty chassis dynamometer.

Figure 8. Volvo VNR with pedal actuator

Figure 9. Volvo VNR on SwRI's heavy-duty chassis dynamometer

Driving Characterization

All tests were completed in a temperature-controlled environment with a target ambient temperature of 73°F. Each dynamometer test cell used a variable speed fan to recreate on-road air flow across the front of the vehicle. Each vehicle test began with determination of dyno coefficients. Vehicle coast downs generated the rolling and frictional coefficients for each benchmark vehicle. All in-use testing used the vehicle curb weight.

Volvo VNR Shift Schedule Characterization

In-use testing for the Volvo I-Shift transmission consisted of upshift and downshift maps. For upshift characterizations the accelerator pedal position was set to a fixed percentage with the vehicle in first gear. The vehicle was allowed to upshift until reaching 70 mph. The speed point in which the vehicle shifted gears was recorded. For downshift characterizations the accelerator pedal position was set to a fixed percentage with the vehicle in 12th gear. The vehicle speed was ramped down to 0 mph and the speed at which the vehicle shifted was recorded. Figures 10 and 11 show the vehicle upshift and downshift characterization maps.

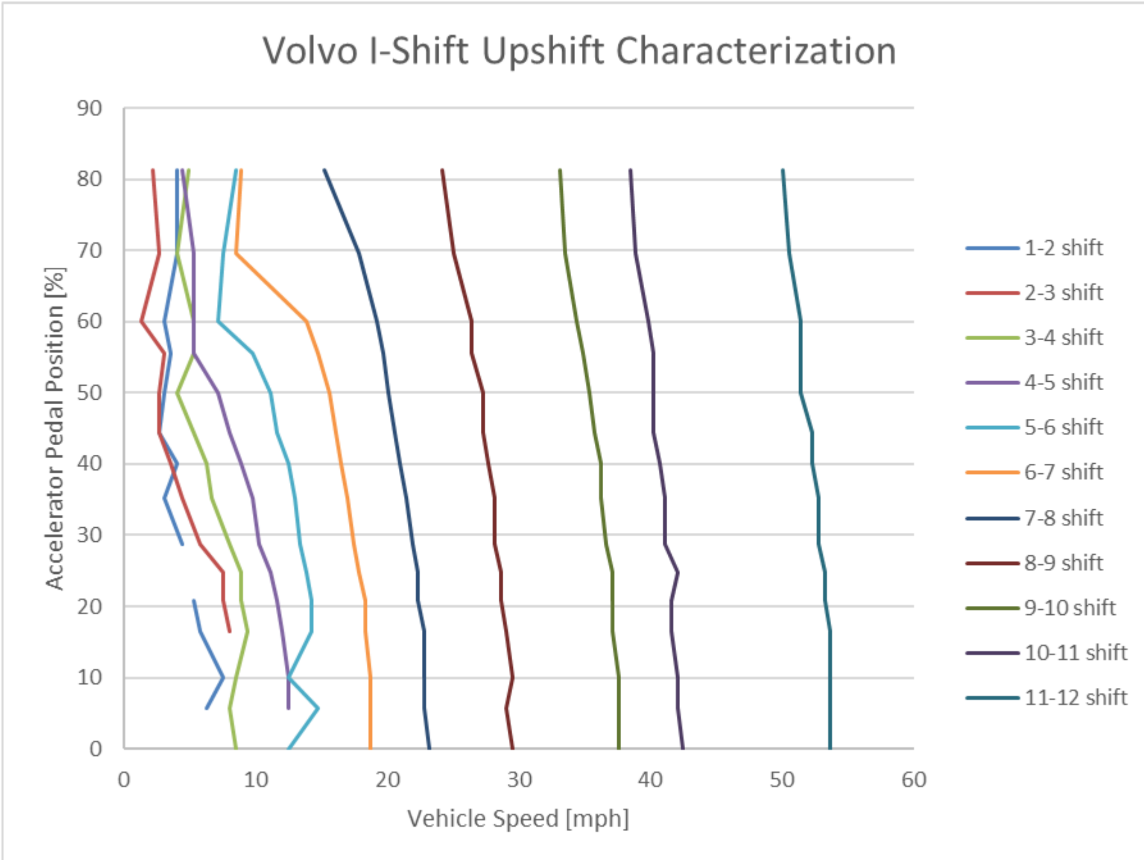


Figure 10. Volvo I-Shift upshift characterization map

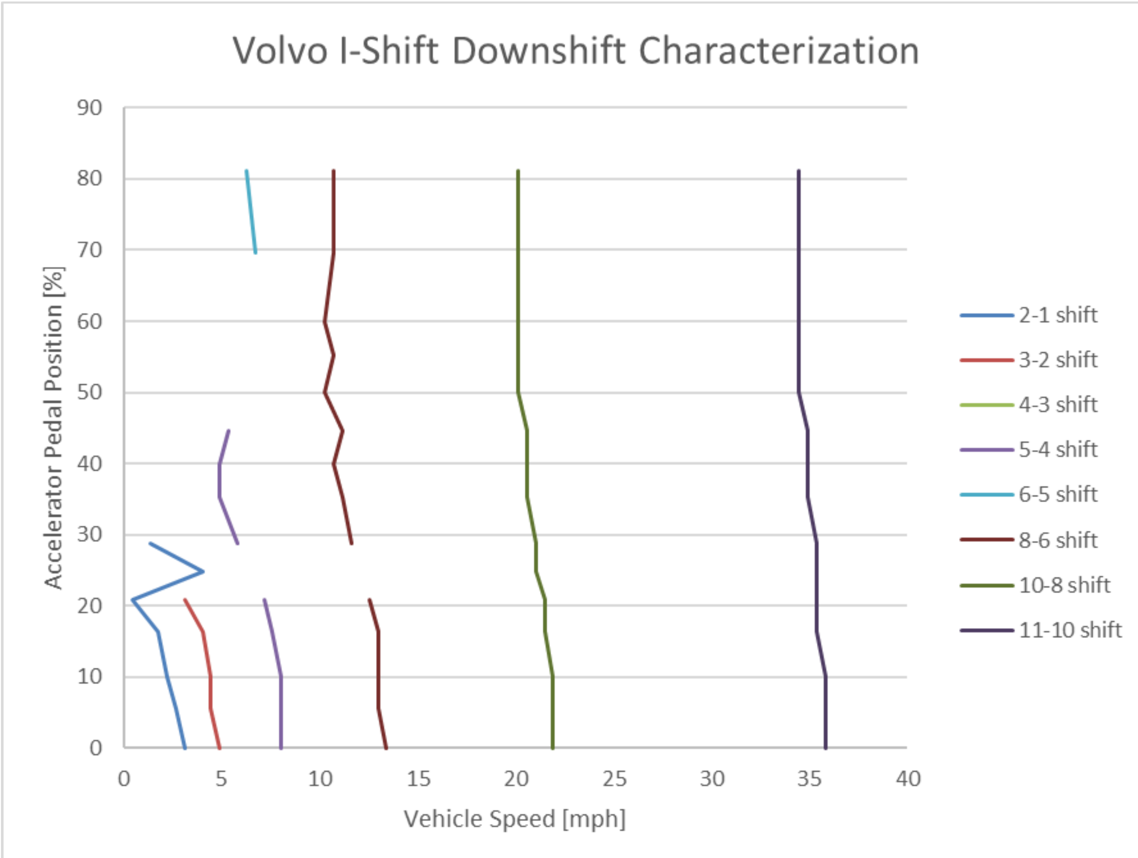


Figure 11. Volvo I-Shift downshift characterization map

Shift Map

Combinations of fixed-pedal-percentage transient-speed and fixed-speed transient-pedal operations were performed to map transmission behavior. The mapping exercises used the dynamometer grade function to induce severe conditions. In-use vehicle testing results are in Appendix C.

Appendix A: Volvo I-Shift Loaded Efficiency – Tabular Data

1st Gear Efficiency					
		Run			
Input Speed (rpm)	Input Torque (Nm)	1	2	3	Efficiency Mean
600	100	91.2%	91.2%	91.1%	91.2%
900	100	90.4%	90.4%	90.3%	90.4%
1200	100	89.5%	89.6%	89.5%	89.5%
1200	200	93.3%	93.3%	93.3%	93.3%
1500	100	88.9%	88.8%	88.9%	88.9%
1500	200	93.0%	93.0%	93.0%	93.0%
1800	100	88.1%	88.1%	88.1%	88.1%
1800	200	92.6%	92.6%	92.6%	92.6%
1800	300	94.0%	94.0%	94.0%	94.0%
2100	100	87.2%	87.3%	87.3%	87.3%
2100	200	92.3%	92.3%	92.2%	92.3%
2100	300	93.8%	93.8%	93.7%	93.8%

2nd Gear Efficiency					
		Run			
Input Speed (rpm)	Input Torque (Nm)	1	2	3	Efficiency Mean
600	100	89.7%	89.6%	89.7%	89.6%
600	200	93.2%	93.0%	93.1%	93.1%
900	100	88.9%	89.0%	89.0%	89.0%
900	200	92.8%	92.7%	92.7%	92.7%
1200	100	88.0%	88.0%	88.1%	88.0%
1200	200	92.3%	92.3%	92.3%	92.3%
1200	300	93.9%	93.9%	93.9%	93.9%
1500	100	86.8%	86.9%	86.6%	86.8%
1500	200	91.8%	91.8%	91.8%	91.8%
1500	300	93.6%	93.6%	93.6%	93.6%
1500	400	94.4%	94.4%	94.4%	94.4%
1800	100	85.6%	85.6%	85.8%	85.7%
1800	200	91.6%	91.3%	91.4%	91.4%
1800	300	93.2%	93.2%	93.3%	93.2%
1800	400	94.1%	94.1%	94.2%	94.1%
2100	100	84.1%	84.3%	84.3%	84.2%
2100	200	90.9%	90.9%	90.9%	90.9%
2100	300	92.9%	92.8%	92.9%	92.8%
2100	400	93.8%	93.8%	93.7%	93.8%

3rd Gear Efficiency					
		Run			
Input Speed (rpm)	**Input Torque (Nm)**	**1**	**2**	**3**	**Efficiency Mean**
600	100	91.3%	91.2%	90.9%	91.1%
600	200	93.5%	93.6%	93.6%	93.6%
600	300	94.5%	94.5%	94.6%	94.5%
900	100	90.3%	90.2%	89.9%	90.1%
900	200	93.2%	93.2%	93.3%	93.2%
900	300	94.5%	94.5%	94.5%	94.5%
900	400	95.0%	95.0%	95.0%	95.0%
1200	100	89.3%	89.4%	89.2%	89.3%
1200	200	93.4%	93.4%	93.3%	93.4%
1200	300	94.3%	94.2%	94.3%	94.3%
1200	400	94.9%	94.9%	94.9%	94.9%
1200	500	95.2%	95.2%	95.2%	95.2%
1500	100	88.2%	88.4%	88.3%	88.3%
1500	200	92.9%	93.0%	93.0%	93.0%
1500	300	94.0%	94.0%	94.0%	94.0%
1500	400	94.7%	94.7%	94.7%	94.7%
1500	500	95.0%	95.0%	95.0%	95.0%
1800	100	87.3%	87.5%	87.4%	87.4%
1800	200	92.5%	92.6%	92.6%	92.5%
1800	300	93.8%	93.8%	93.8%	93.8%
1800	400	94.6%	94.6%	94.6%	94.6%
1800	500	95.0%	94.9%	95.0%	95.0%
2100	100	86.4%	86.6%	86.5%	86.5%
2100	200	92.1%	92.2%	92.2%	92.2%
2100	300	94.0%	94.0%	94.0%	94.0%
2100	400	94.5%	94.5%	94.5%	94.5%
2100	500	95.0%	95.0%	95.0%	95.0%

4th Gear Efficiency					
		Run			
Input Speed (rpm)	**Input Torque (Nm)**	**1**	**2**	**3**	**Efficiency Mean**
600	100	89.6%	89.3%	89.4%	89.4%
600	200	93.4%	93.3%	93.3%	93.4%
600	300	94.2%	94.2%	94.2%	94.2%
600	400	94.9%	94.9%	94.9%	94.9%
600	500	95.3%	95.3%	95.3%	95.3%
900	100	88.2%	88.2%	88.1%	88.2%
900	200	92.9%	92.9%	92.9%	92.9%
900	300	94.0%	94.0%	94.0%	94.0%
900	400	94.8%	94.8%	94.8%	94.8%
900	500	95.3%	95.3%	95.2%	95.2%
1200	100	86.9%	87.0%	86.4%	86.8%
1200	200	92.4%	92.4%	92.0%	92.3%
1200	300	94.2%	94.1%	93.9%	94.1%
1200	400	94.6%	94.7%	94.7%	94.7%
1200	500	95.2%	95.2%	95.2%	95.2%
1500	100	85.2%	85.3%	84.4%	85.0%
1500	200	91.6%	91.7%	91.3%	91.5%
1500	300	93.7%	93.7%	93.5%	93.6%
1500	400	94.7%	94.4%	94.4%	94.5%
1500	500	95.1%	95.1%	95.1%	95.1%
1800	100	84.0%	84.1%	83.6%	83.9%
1800	200	91.0%	91.1%	90.9%	91.0%
1800	300	93.4%	93.4%	93.2%	93.3%
1800	400	94.6%	94.5%	94.4%	94.5%
1800	500	94.9%	94.9%	95.0%	95.0%
2100	100	82.3%	82.3%	82.4%	82.3%
2100	200	90.3%	90.4%	90.3%	90.3%
2100	300	93.0%	93.0%	92.9%	93.0%
2100	400	94.3%	94.3%	94.2%	94.3%
2100	500	94.7%	94.7%	94.7%	94.7%

5th Gear Efficiency					
		Run			
Input Speed (rpm)	**Input Torque (Nm)**	**1**	**2**	**3**	**Efficiency Mean**
600	100	89.4%	89.5%	88.0%	88.9%
600	200	93.3%	93.3%	92.5%	93.0%
600	300	94.4%	94.4%	93.9%	94.2%
600	400	94.6%	94.5%	94.6%	94.5%
600	500	94.9%	94.9%	94.9%	94.9%
600	750	95.3%	95.3%	95.3%	95.3%
900	100	88.0%	88.3%	86.8%	87.7%
900	200	92.8%	92.8%	92.0%	92.5%
900	300	94.3%	94.3%	93.7%	94.1%
900	400	95.0%	94.9%	94.5%	94.8%
900	500	94.9%	94.9%	94.9%	94.9%
900	750	95.3%	95.1%	95.2%	95.2%
1200	100	87.0%	87.1%	85.5%	86.5%
1200	200	92.4%	92.4%	91.5%	92.1%
1200	300	94.1%	94.1%	93.5%	93.9%
1200	400	94.9%	94.8%	94.4%	94.7%
1200	500	95.3%	95.2%	94.9%	95.2%
1200	750	95.4%	95.4%	95.5%	95.4%
1500	100	85.6%	85.7%	84.0%	85.1%
1500	200	91.8%	91.8%	91.0%	91.5%
1500	300	93.8%	93.7%	93.2%	93.6%
1500	400	94.7%	94.7%	94.2%	94.5%
1500	500	95.3%	95.2%	94.8%	95.1%
1500	750	95.4%	95.5%	95.5%	95.5%
1800	100	84.6%	84.4%	83.1%	84.0%
1800	200	91.3%	91.2%	90.5%	91.0%
1800	300	93.5%	93.4%	92.9%	93.3%
1800	400	94.5%	94.4%	94.1%	94.3%
1800	500	95.1%	95.0%	94.7%	94.9%
1800	750	95.4%	95.4%	95.5%	95.5%
2100	100	83.4%	83.3%	81.8%	82.8%
2100	200	90.7%	90.7%	90.0%	90.5%
2100	300	93.2%	93.1%	92.6%	93.0%
2100	400	94.3%	94.2%	93.9%	94.1%
2100	500	95.0%	94.9%	94.6%	94.8%
2100	750	95.4%	95.4%	95.4%	95.4%

6th Gear Efficiency					
		Run			
Input Speed (rpm)	Input Torque (Nm)	1	2	3	Efficiency Mean
600	100	88.2%	87.8%	86.9%	87.6%
600	200	93.5%	93.3%	92.9%	93.2%
600	300	95.2%	95.1%	94.8%	95.1%
600	400	96.0%	96.0%	95.8%	95.9%
600	500	96.1%	96.2%	96.3%	96.2%
600	750	96.8%	96.8%	96.9%	96.8%
600	1000	97.0%	97.1%	97.1%	97.1%
900	100	86.1%	85.9%	84.7%	85.6%
900	200	92.5%	92.5%	91.8%	92.3%
900	300	94.6%	94.6%	94.2%	94.5%
900	400	95.6%	95.6%	95.3%	95.5%
900	500	96.2%	96.2%	95.9%	96.1%
900	750	96.6%	96.6%	96.7%	96.6%
900	1000	96.9%	96.8%	97.0%	96.9%
1200	100	84.4%	84.4%	82.5%	83.8%
1200	200	91.7%	91.7%	90.9%	91.4%
1200	300	94.1%	94.1%	93.6%	93.9%
1200	400	95.3%	95.3%	94.9%	95.1%
1200	500	96.0%	96.0%	95.6%	95.9%
1200	750	96.9%	96.6%	96.6%	96.7%
1200	1000	96.9%	96.9%	97.0%	96.9%
1500	100	82.1%	82.1%	80.6%	81.6%
1500	200	90.6%	90.6%	89.9%	90.4%
1500	300	93.4%	93.4%	92.9%	93.2%
1500	400	94.8%	94.8%	94.4%	94.6%
1500	500	95.6%	95.6%	95.2%	95.5%
1500	750	96.6%	96.6%	96.4%	96.6%
1500	1000	96.8%	96.8%	96.9%	96.8%
1800	100	79.9%	79.7%	78.3%	79.3%
1800	200	89.5%	89.4%	88.7%	89.2%
1800	300	92.7%	92.7%	92.1%	92.5%
1800	400	94.3%	94.2%	93.8%	94.1%
1800	500	95.2%	95.2%	94.8%	95.1%
1800	750	96.4%	96.4%	96.1%	96.3%
1800	1000	96.6%	96.7%	96.7%	96.7%

6th Gear Efficiency					
		Run			
Input Speed (rpm)	Input Torque (Nm)	1	2	3	Efficiency Mean
2100	100	77.4%	77.6%	75.9%	77.0%
2100	200	88.3%	88.3%	87.5%	88.0%
2100	300	91.9%	91.9%	91.4%	91.7%
2100	400	93.7%	93.6%	93.3%	93.5%
2100	500	94.8%	94.7%	94.4%	94.6%
2100	750	96.1%	96.1%	95.9%	96.0%
2100	1000	96.5%	96.5%	96.6%	96.5%

7th Gear Efficiency					
		Run			
Input Speed (rpm)	Input Torque (Nm)	1	2	3	Efficiency Mean
600	100	89.4%	89.2%	88.7%	89.1%
600	200	93.8%	93.7%	93.5%	93.7%
600	300	95.3%	95.2%	95.0%	95.2%
600	400	96.0%	95.9%	95.8%	95.9%
600	500	96.4%	96.4%	96.3%	96.4%
600	750	96.7%	96.6%	96.9%	96.7%
600	1000	97.0%	97.0%	97.1%	97.0%
900	100	88.4%	88.2%	87.4%	88.0%
900	200	93.4%	93.3%	92.9%	93.2%
900	300	95.1%	95.0%	94.8%	94.9%
900	400	95.9%	95.8%	95.6%	95.8%
900	500	96.4%	96.3%	96.2%	96.3%
900	750	97.0%	96.9%	96.8%	96.9%
900	1000	97.0%	97.0%	97.1%	97.1%
1200	100	87.5%	87.2%	86.4%	87.0%
1200	200	93.0%	92.9%	92.5%	92.8%
1200	300	94.8%	94.8%	94.5%	94.7%
1200	400	95.7%	95.7%	95.5%	95.6%
1200	500	96.3%	96.2%	96.1%	96.2%
1200	750	97.0%	96.9%	96.8%	96.9%
1200	1000	97.3%	97.2%	97.1%	97.2%
1500	100	86.3%	86.2%	85.4%	86.0%
1500	200	92.5%	92.5%	92.0%	92.3%
1500	300	94.6%	94.5%	94.3%	94.4%

7th Gear Efficiency					
		Run			
Input Speed (rpm)	**Input Torque (Nm)**	**1**	**2**	**3**	**Efficiency Mean**
1500	400	95.6%	95.5%	95.3%	95.5%
1500	500	96.2%	96.1%	96.0%	96.1%
1500	750	96.9%	96.9%	96.8%	96.9%
1500	1000	97.3%	97.2%	97.1%	97.2%
1800	100	85.3%	85.2%	84.7%	85.1%
1800	200	92.0%	92.0%	91.6%	91.9%
1800	300	94.3%	94.3%	94.0%	94.2%
1800	400	95.4%	95.3%	95.1%	95.3%
1800	500	96.0%	96.0%	95.8%	96.0%
1800	750	96.9%	96.8%	96.7%	96.8%
1800	1000	97.2%	97.2%	97.1%	97.2%
2100	100	84.5%	84.4%	83.8%	84.2%
2100	200	91.6%	91.6%	91.2%	91.5%
2100	300	94.0%	94.0%	93.7%	93.9%
2100	400	95.2%	95.1%	95.0%	95.1%
2100	500	95.9%	95.8%	95.7%	95.8%
2100	750	96.8%	96.7%	96.6%	96.7%
2100	1000	97.2%	97.1%	97.1%	97.1%

8th Gear Efficiency					
		Run			
Input Speed (rpm)	**Input Torque (Nm)**	**1**	**2**	**3**	**Efficiency Mean**
600	100	86.6%	86.3%	86.7%	86.6%
600	200	92.5%	92.3%	92.5%	92.4%
600	300	94.4%	94.3%	94.5%	94.4%
600	400	95.4%	95.3%	95.4%	95.4%
600	500	96.0%	96.0%	96.0%	96.0%
600	750	96.7%	96.7%	96.7%	96.7%
600	1000	97.1%	97.0%	97.0%	97.0%
900	100	85.1%	84.9%	85.0%	85.0%
900	200	91.8%	91.8%	91.7%	91.8%
900	300	94.0%	94.0%	94.0%	94.0%
900	400	95.1%	95.1%	95.1%	95.1%
900	500	95.9%	95.8%	95.8%	95.8%
900	750	96.7%	96.7%	96.7%	96.7%

8th Gear Efficiency					
		Run			
Input Speed (rpm)	**Input Torque (Nm)**	**1**	**2**	**3**	**Efficiency Mean**
900	1000	97.1%	97.1%	97.0%	97.1%
1200	100	83.6%	83.8%	83.7%	83.7%
1200	200	91.2%	91.2%	91.1%	91.2%
1200	300	93.7%	93.7%	93.6%	93.7%
1200	400	94.9%	95.0%	94.9%	94.9%
1200	500	95.7%	95.7%	95.7%	95.7%
1200	750	96.6%	96.7%	96.6%	96.6%
1200	1000	97.1%	97.1%	97.0%	97.1%
1500	100	82.2%	82.4%	82.4%	82.4%
1500	200	90.5%	90.6%	90.5%	90.5%
1500	300	93.3%	93.3%	93.3%	93.3%
1500	400	94.6%	94.7%	94.6%	94.7%
1500	500	95.5%	95.6%	95.5%	95.5%
1500	750	96.5%	96.6%	96.5%	96.6%
1500	1000	97.0%	97.1%	97.0%	97.0%
1800	100	80.9%	80.9%	80.7%	80.8%
1800	200	89.8%	89.9%	89.8%	89.8%
1800	300	92.9%	92.9%	92.8%	92.9%
1800	400	94.3%	94.4%	94.3%	94.3%
1800	500	95.3%	95.3%	95.3%	95.3%
1800	750	96.4%	96.5%	96.4%	96.4%
1800	1000	97.0%	97.0%	96.9%	97.0%
2100	100	79.3%	79.6%	79.4%	79.4%
2100	200	89.0%	89.1%	89.1%	89.1%
2100	300	92.3%	92.4%	92.3%	92.3%
2100	400	94.0%	94.0%	93.9%	94.0%
2100	500	95.0%	95.0%	95.0%	95.0%
2100	750	96.3%	96.3%	96.3%	96.3%
2100	1000	96.8%	96.9%	96.8%	96.8%

9th Gear Efficiency					
		Run			
Input Speed (rpm)	Input Torque (Nm)	1	2	3	Efficiency Mean
600	100	86.1%	85.8%	86.4%	86.1%
600	200	92.2%	92.1%	92.4%	92.3%
600	300	94.3%	94.2%	94.4%	94.3%
600	400	95.3%	95.2%	95.4%	95.3%
600	500	95.9%	95.9%	96.0%	95.9%
600	750	96.7%	96.7%	96.7%	96.7%
600	1000	97.1%	97.1%	97.1%	97.1%
600	1250	97.4%	97.3%	97.4%	97.4%
900	100	84.9%	84.7%	85.2%	84.9%
900	200	91.7%	91.6%	91.9%	91.8%
900	300	94.0%	93.9%	94.2%	94.0%
900	400	95.2%	95.1%	95.3%	95.2%
900	500	95.8%	95.8%	95.9%	95.8%
900	750	96.7%	96.7%	96.8%	96.7%
900	1000	97.2%	97.1%	97.2%	97.2%
900	1250	97.4%	97.4%	97.4%	97.4%
1200	100	84.1%	83.6%	84.4%	84.0%
1200	200	91.4%	91.2%	91.5%	91.4%
1200	300	93.8%	93.7%	93.9%	93.8%
1200	400	95.0%	95.0%	95.1%	95.0%
1200	500	95.8%	95.7%	95.8%	95.8%
1200	750	96.7%	96.6%	96.7%	96.7%
1200	1000	97.2%	97.1%	97.2%	97.2%
1200	1250	97.5%	97.4%	97.5%	97.4%
1500	100	82.8%	83.6%	83.3%	83.2%
1500	200	90.9%	90.7%	91.1%	90.9%
1500	300	93.5%	93.5%	93.7%	93.5%
1500	400	94.8%	94.8%	94.9%	94.8%
1500	500	95.6%	95.6%	95.7%	95.6%
1500	750	96.6%	96.6%	96.7%	96.6%
1500	1000	97.1%	97.1%	97.2%	97.1%
1500	1250	97.4%	97.4%	97.4%	97.4%
1800	100	81.9%	82.6%	82.2%	82.2%
1800	200	90.4%	90.3%	90.6%	90.4%
1800	300	93.2%	93.2%	93.4%	93.3%
1800	400	94.6%	94.6%	94.7%	94.7%

9th Gear Efficiency					
		Run			
Input Speed (rpm)	**Input Torque (Nm)**	**1**	**2**	**3**	**Efficiency Mean**
1800	500	95.5%	95.4%	95.5%	95.5%
1800	750	96.6%	96.5%	96.3%	96.5%
1800	1000	97.1%	97.1%	96.9%	97.0%
1800	1250	97.4%	97.4%	97.2%	97.3%
2100	100	80.8%	81.4%	81.1%	81.1%
2100	200	89.8%	89.7%	90.1%	89.9%
2100	300	92.9%	92.8%	93.0%	92.9%
2100	400	94.4%	94.3%	94.5%	94.4%
2100	500	95.3%	95.2%	95.4%	95.3%
2100	750	96.5%	96.4%	96.2%	96.4%
2100	1000	97.0%	97.0%	96.8%	97.0%
2100	1250	97.4%	97.3%	97.2%	97.3%

10th Gear Efficiency					
		Run			
Input Speed (rpm)	**Input Torque (Nm)**	**1**	**2**	**3**	**Efficiency Mean**
600	100	82.6%	82.2%	82.8%	82.5%
600	200	90.6%	90.5%	90.8%	90.6%
600	300	93.3%	93.2%	93.5%	93.3%
600	400	94.6%	94.6%	94.8%	94.7%
600	500	95.5%	95.4%	95.6%	95.5%
600	750	96.5%	96.5%	96.6%	96.5%
600	1000	97.0%	97.0%	97.1%	97.0%
600	1250	97.3%	97.3%	97.4%	97.3%
600	1500	97.5%	97.5%	97.5%	97.5%
900	100	81.1%	81.8%	81.8%	81.6%
900	200	90.0%	89.8%	90.2%	90.0%
900	300	93.0%	92.9%	93.2%	93.0%
900	400	94.4%	94.4%	94.6%	94.5%
900	500	95.3%	95.3%	95.5%	95.4%
900	750	96.5%	96.5%	96.6%	96.5%
900	1000	97.1%	97.0%	97.1%	97.1%
900	1250	97.4%	97.4%	97.4%	97.4%
900	1500	97.6%	97.6%	97.6%	97.6%
1200	100	79.8%	80.4%	79.7%	80.0%

10th Gear Efficiency					
		Run			
Input Speed (rpm)	Input Torque (Nm)	1	2	3	Efficiency Mean
1200	200	89.5%	89.2%	89.6%	89.4%
1200	300	92.6%	92.6%	92.8%	92.7%
1200	400	94.3%	94.2%	94.4%	94.3%
1200	500	95.3%	95.2%	95.4%	95.3%
1200	750	96.5%	96.5%	96.6%	96.5%
1200	1000	97.1%	97.1%	97.1%	97.1%
1200	1250	97.4%	97.4%	97.5%	97.4%
1200	1500	97.7%	97.6%	97.7%	97.6%
1500	100	78.0%	78.9%	78.4%	78.4%
1500	200	88.6%	88.6%	88.9%	88.7%
1500	300	92.2%	92.1%	92.3%	92.2%
1500	400	93.9%	93.9%	94.1%	94.0%
1500	500	95.0%	95.0%	95.1%	95.0%
1500	750	96.4%	96.4%	96.4%	96.4%
1500	1000	97.0%	97.0%	97.1%	97.0%
1500	1250	97.4%	97.4%	97.4%	97.4%
1500	1500	97.6%	97.6%	97.7%	97.6%
1800	100	76.5%	77.5%	77.4%	77.1%
1800	200	88.0%	88.4%	88.2%	88.2%
1800	300	91.7%	91.6%	91.9%	91.7%
1800	400	93.6%	93.5%	93.7%	93.6%
1800	500	94.7%	94.7%	94.9%	94.8%
1800	750	96.2%	96.2%	96.3%	96.2%
1800	1000	96.9%	96.9%	97.0%	96.9%
1800	1250	97.3%	97.3%	97.4%	97.3%
1800	1500	97.6%	97.6%	97.6%	97.6%
2100	100	74.8%	75.7%	75.6%	75.4%
2100	200	87.1%	87.6%	87.4%	87.3%
2100	300	91.2%	91.1%	91.3%	91.2%
2100	400	93.2%	93.1%	93.3%	93.2%
2100	500	94.4%	94.4%	94.6%	94.5%
2100	750	96.1%	96.0%	96.1%	96.1%
2100	1000	96.8%	96.8%	96.9%	96.8%
2100	1250	97.3%	97.2%	97.3%	97.3%
2100	1500	97.5%	97.5%	97.6%	97.5%

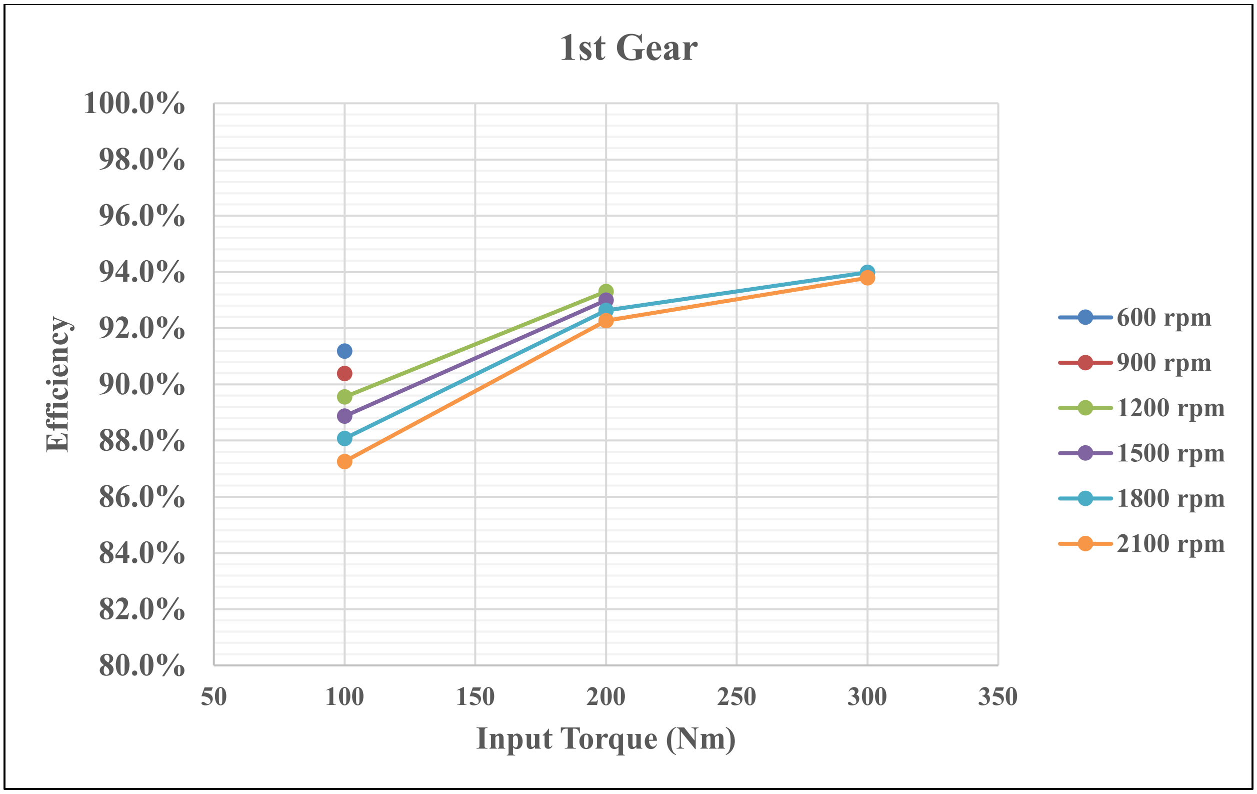
11th Gear Efficiency					
		Run			
Input Speed (rpm)	Input Torque (Nm)	1	2	3	Efficiency Mean
600	100	80.16%	79.80%	80.66%	80.21%
600	200	89.34%	89.41%	89.79%	89.51%
600	300	92.41%	92.46%	92.73%	92.53%
600	400	93.92%	94.00%	94.19%	94.04%
600	500	94.86%	94.90%	95.07%	94.94%
600	750	96.08%	96.12%	96.24%	96.15%
600	1000	96.69%	96.73%	96.81%	96.74%
600	1250	97.06%	97.09%	97.15%	97.10%
600	1500	97.31%	97.32%	97.38%	97.34%
900	100	78.72%	78.72%	79.39%	78.94%
900	200	88.84%	88.84%	89.22%	88.97%
900	300	92.17%	92.18%	92.45%	92.27%
900	400	93.80%	93.82%	94.03%	93.88%
900	500	94.78%	94.80%	94.96%	94.85%
900	750	96.09%	96.10%	96.21%	96.13%
900	1000	96.73%	96.75%	96.83%	96.77%
900	1250	97.12%	97.13%	97.20%	97.15%
900	1500	97.38%	97.39%	97.44%	97.40%
1200	100	77.56%	77.34%	77.98%	77.63%
1200	200	88.40%	88.26%	88.64%	88.44%
1200	300	91.97%	91.85%	92.12%	91.98%
1200	400	93.74%	93.63%	93.80%	93.72%
1200	500	94.78%	94.68%	94.81%	94.76%
1200	750	96.15%	96.05%	96.15%	96.12%
1200	1000	96.82%	96.74%	96.81%	96.79%
1200	1250	97.19%	97.15%	97.21%	97.18%
1200	1500	97.43%	97.42%	97.47%	97.44%
1500	100	76.13%	75.90%	76.63%	76.22%
1500	200	87.79%	87.64%	88.10%	87.84%
1500	300	91.56%	91.51%	91.79%	91.62%
1500	400	93.43%	93.40%	93.60%	93.48%
1500	500	94.53%	94.52%	94.69%	94.58%
1500	750	95.99%	96.00%	96.13%	96.04%
1500	1000	96.71%	96.72%	96.83%	96.75%
1500	1250	97.14%	97.14%	97.22%	97.17%

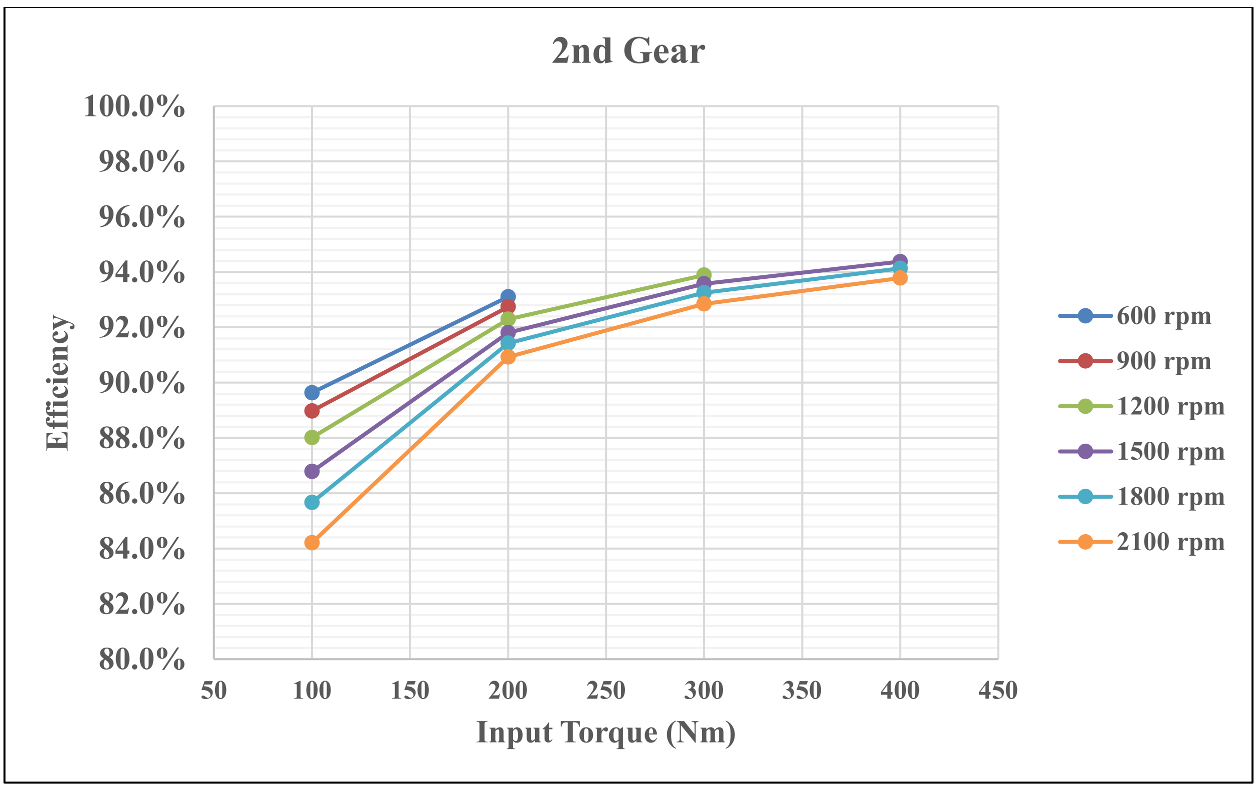
11th Gear Efficiency					
		Run			
Input Speed (rpm)	**Input Torque (Nm)**	**1**	**2**	**3**	**Efficiency Mean**
1500	1500	97.42%	97.42%	97.48%	97.44%
1800	100	74.86%	74.51%	75.47%	74.94%
1800	200	87.11%	87.08%	87.45%	87.21%
1800	300	91.15%	91.13%	91.43%	91.24%
1800	400	93.14%	93.13%	93.38%	93.21%
1800	500	94.32%	94.30%	94.46%	94.36%
1800	750	95.87%	95.87%	95.99%	95.91%
1800	1000	96.64%	96.64%	96.74%	96.67%
1800	1250	97.09%	97.09%	97.17%	97.11%
1800	1500	97.39%	97.38%	97.45%	97.41%
2100	100	73.36%	73.46%	74.04%	73.62%
2100	200	86.39%	86.45%	86.89%	86.58%
2100	300	90.71%	90.74%	91.07%	90.84%
2100	400	92.85%	92.85%	93.13%	92.94%
2100	500	94.12%	94.11%	94.26%	94.16%
2100	750	95.77%	95.77%	95.88%	95.81%
2100	1000	96.58%	96.57%	96.66%	96.61%
2100	1250	97.05%	97.05%	97.12%	97.07%
2100	1500	97.36%	97.35%	97.42%	97.38%

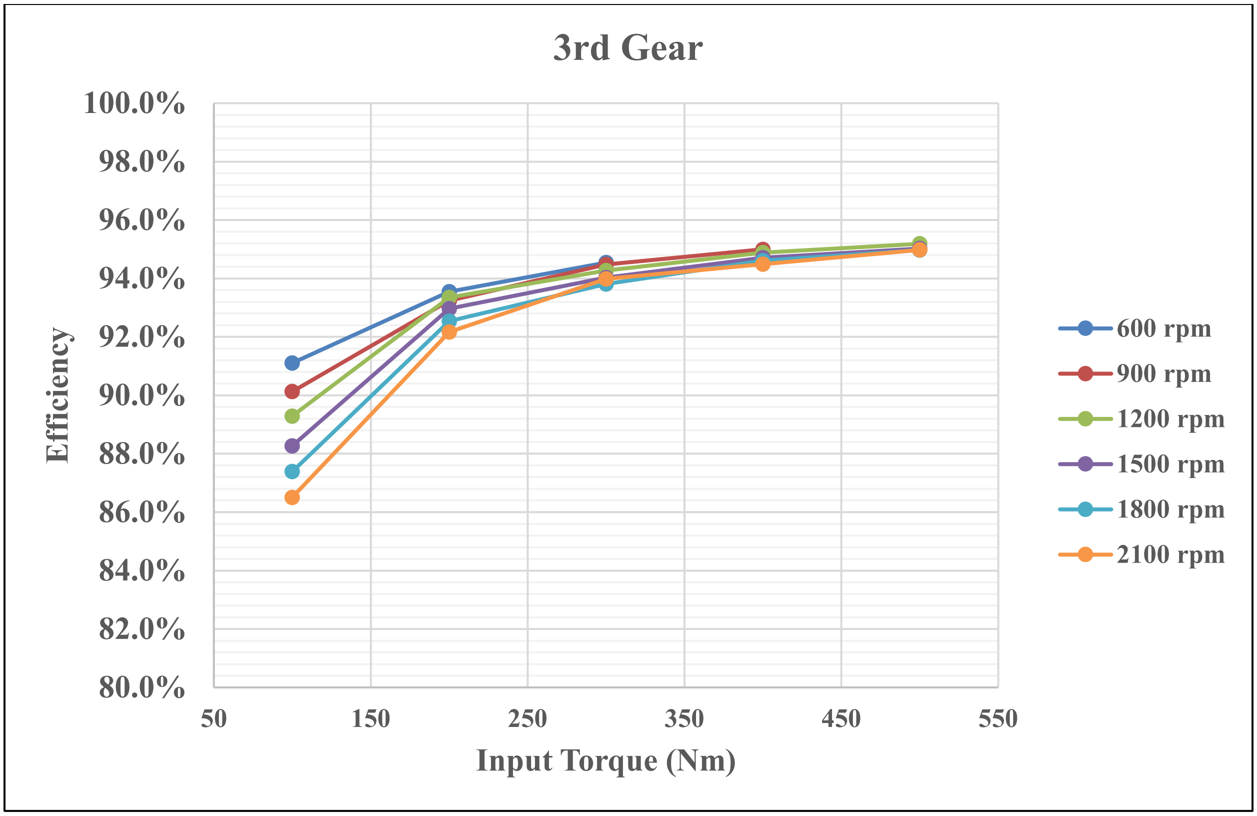
12th Gear Efficiency					
		Run			
Input Speed (rpm)	**Input Torque (Nm)**	**1**	**2**	**3**	**Efficiency Mean**
600	100	76.2%	75.4%	76.7%	76.1%
600	200	88.2%	87.7%	88.4%	88.1%
600	300	92.1%	91.9%	92.3%	92.1%
600	400	94.1%	93.9%	94.2%	94.1%
600	500	95.4%	95.2%	95.4%	95.3%
600	750	97.0%	96.8%	97.0%	96.9%
600	1000	97.8%	97.6%	97.8%	97.7%
600	1250	98.2%	98.1%	98.3%	98.2%
600	1500	98.5%	98.5%	98.6%	98.5%
900	100	73.7%	73.3%	74.4%	73.8%
900	200	86.9%	86.8%	87.2%	87.0%
900	300	91.3%	91.2%	91.5%	91.3%

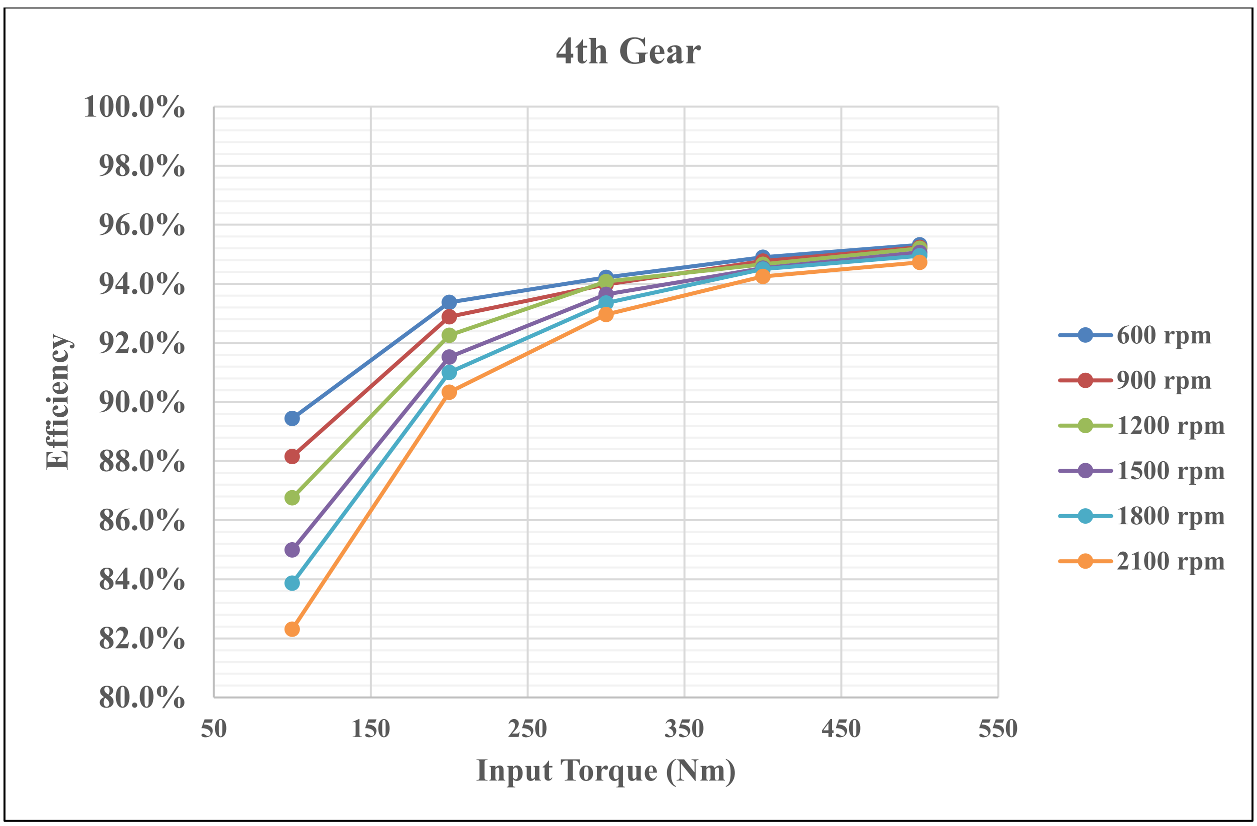
12th Gear Efficiency					
		Run			
Input Speed (rpm)	Input Torque (Nm)	1	2	3	Efficiency Mean
900	400	93.5%	93.4%	93.7%	93.5%
900	500	94.8%	94.8%	95.0%	94.9%
900	750	96.7%	96.6%	96.7%	96.7%
900	1000	97.5%	97.4%	97.6%	97.5%
900	1250	98.1%	98.0%	98.1%	98.0%
900	1500	98.4%	98.3%	98.4%	98.4%
1200	100	71.3%	71.5%	72.4%	71.8%
1200	200	85.8%	85.9%	86.2%	86.0%
1200	300	90.6%	90.6%	90.9%	90.7%
1200	400	93.0%	93.0%	93.2%	93.1%
1200	500	94.4%	94.4%	94.6%	94.5%
1200	750	96.3%	96.3%	96.5%	96.4%
1200	1000	97.3%	97.3%	97.4%	97.3%
1200	1250	97.9%	97.8%	97.9%	97.9%
1200	1500	98.2%	98.2%	98.3%	98.3%
1500	100	69.7%	69.1%	70.4%	69.7%
1500	200	84.9%	84.7%	85.1%	84.9%
1500	300	90.0%	89.8%	90.2%	90.0%
1500	400	92.5%	92.4%	92.6%	92.5%
1500	500	94.1%	94.0%	94.2%	94.1%
1500	750	96.1%	96.0%	96.2%	96.1%
1500	1000	97.1%	97.1%	97.2%	97.1%
1500	1250	97.7%	97.7%	97.8%	97.7%
1500	1500	98.1%	98.1%	98.2%	98.1%
1800	100	67.7%	69.6%	68.1%	68.5%
1800	200	83.9%	84.8%	84.0%	84.2%
1800	300	89.3%	89.9%	89.4%	89.5%
1800	400	92.0%	92.5%	92.1%	92.2%
1800	500	93.7%	94.0%	93.7%	93.8%
1800	750	95.8%	96.0%	95.8%	95.9%
1800	1000	96.9%	97.0%	96.9%	96.9%
1800	1250	97.5%	97.6%	97.6%	97.6%
1800	1500	98.0%	98.0%	98.0%	98.0%
2100	100	66.3%	64.5%	65.4%	65.4%
2100	200	82.8%	82.4%	82.9%	82.7%

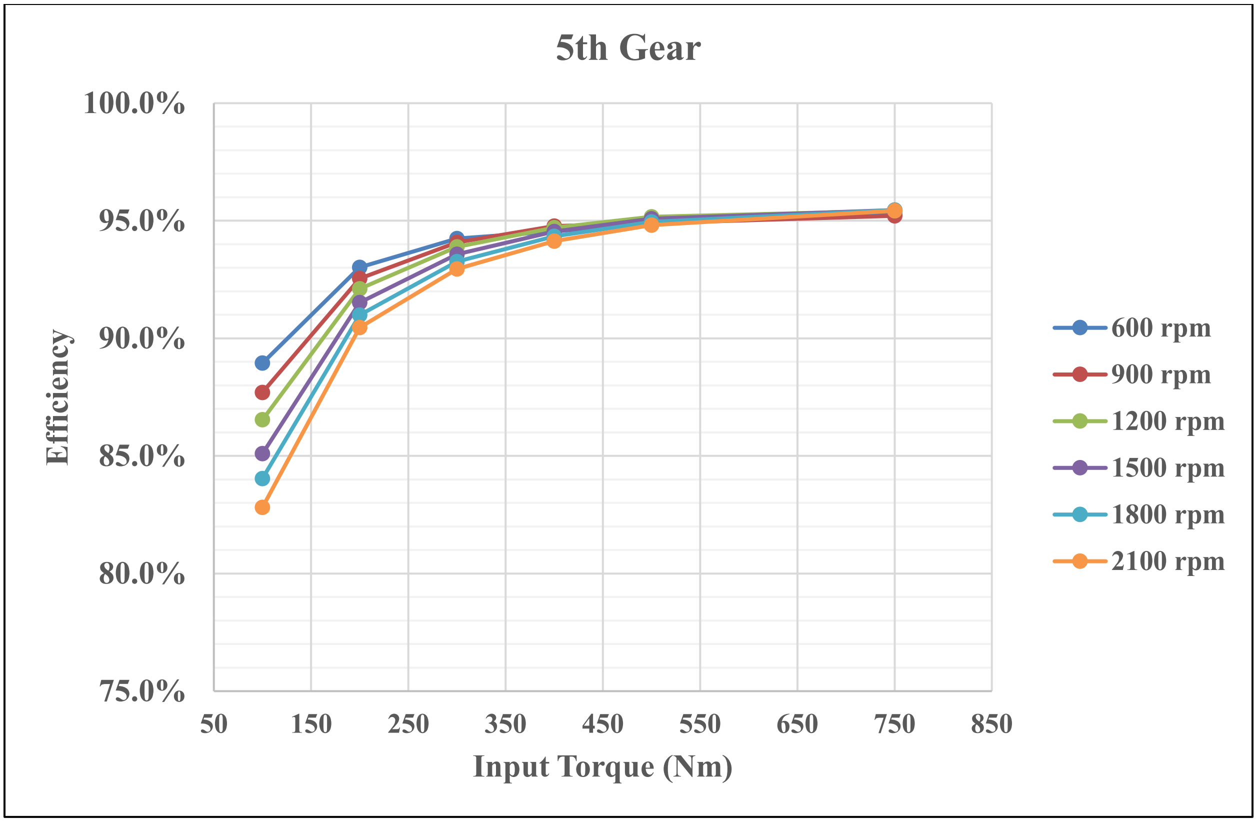
12th Gear Efficiency					
		Run			
Input Speed (rpm)	**Input Torque (Nm)**	**1**	**2**	**3**	**Efficiency Mean**
2100	300	88.6%	88.3%	88.6%	88.5%
2100	400	91.5%	91.2%	91.5%	91.4%
2100	500	93.2%	93.0%	93.2%	93.1%
2100	750	95.5%	95.4%	95.5%	95.5%
2100	1000	96.7%	96.6%	96.7%	96.6%
2100	1250	97.3%	97.3%	97.4%	97.3%
2100	1500	97.8%	97.8%	97.8%	97.8%

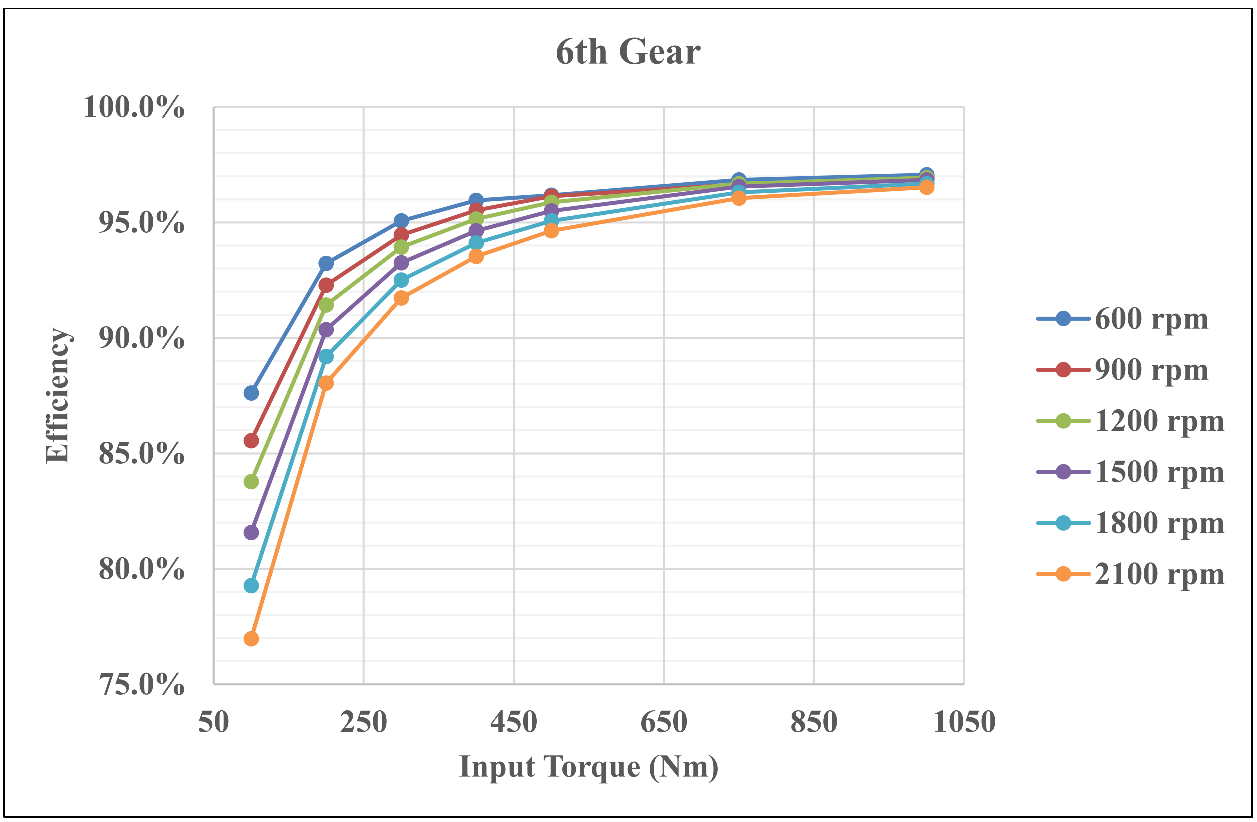

1st Gear
100.0%
98.0%
96.0%
94.0%
92.0%
90.0%
88.0%
86.0%
84.0%
82.0%
80.0%
Efficiency
50
100
150
200
250
300
350
Input Torque (Nm)
600 rpm
900 rpm
1200 rpm
1500 rpm
1800 rpm
2100 rpm

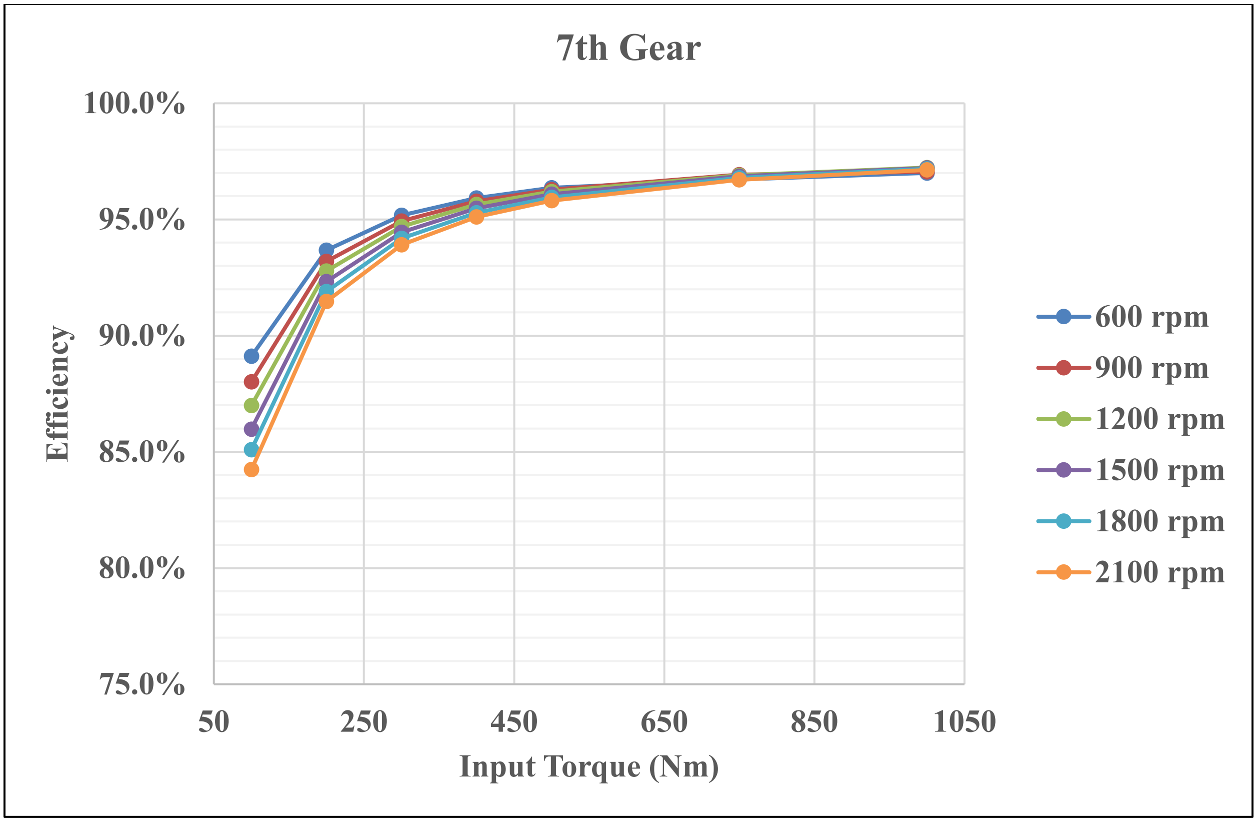

2nd Gear
100.0%
98.0%
96.0%
94.0%
92.0%
90.0%
88.0%
86.0%
84.0%
82.0%
80.0%
Efficiency
50
100
150
200
250
300
350
400
450
Input Torque (Nm)
600 rpm
900 rpm
1200 rpm
1500 rpm
1800 rpm
2100 rpm

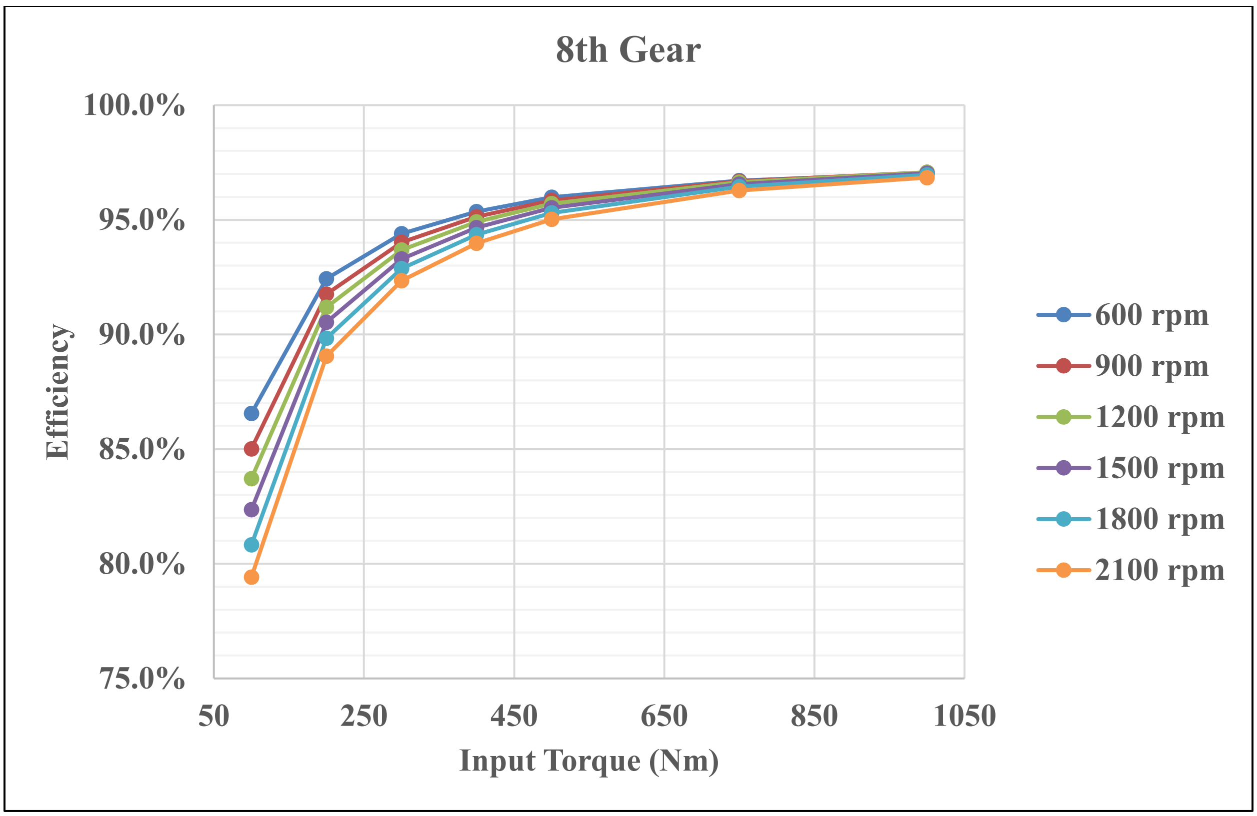

3rd Gear
100.0%
98.0%
96.0%
94.0%
92.0%
90.0%
88.0%
86.0%
84.0%
82.0%
80.0%
Efficiency
50
150
250
350
450
550
Input Torque (Nm)
600 rpm
900 rpm
1200 rpm
1500 rpm
1800 rpm
2100 rpm

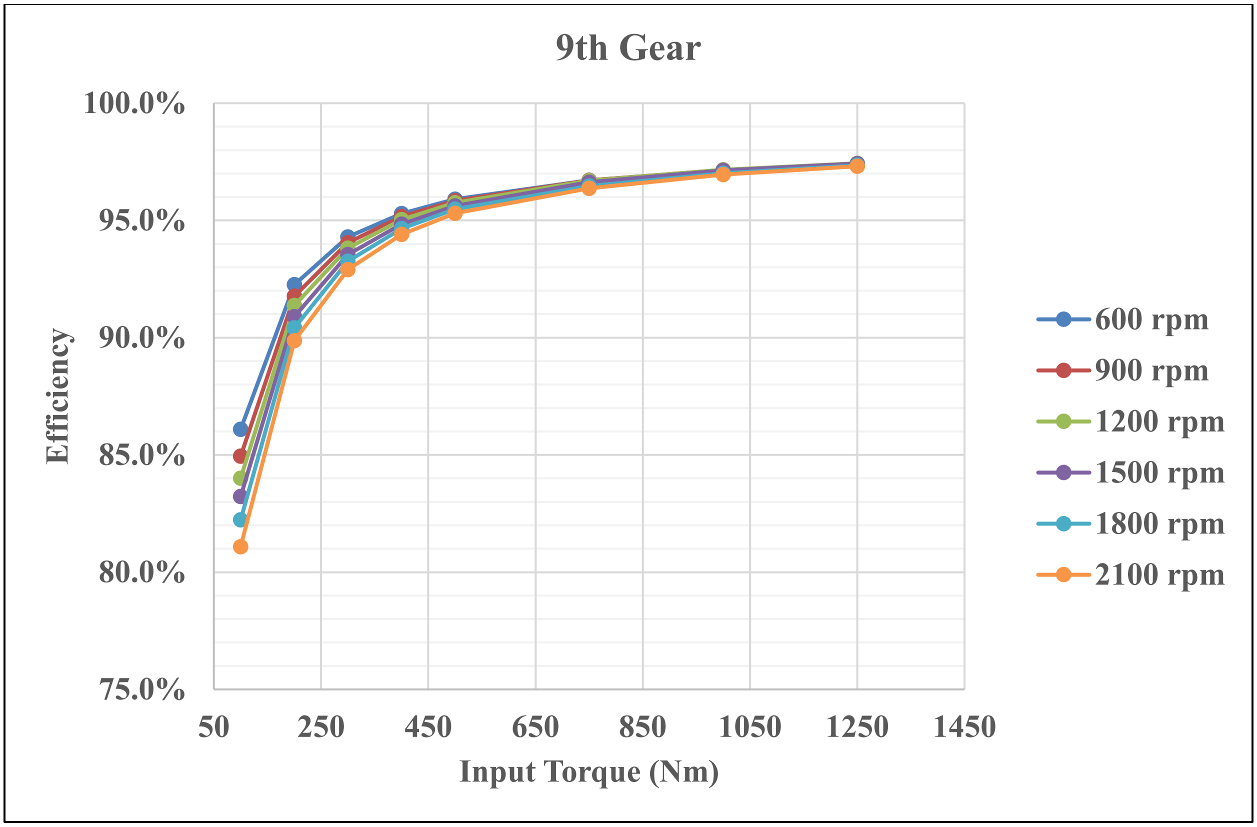

4th Gear
100.0%
98.0%
96.0%
94.0%
92.0%
90.0%
88.0%
86.0%
84.0%
82.0%
80.0%
Efficiency
50
150
250
350
450
550
Input Torque (Nm)
600 rpm
900 rpm
1200 rpm
1500 rpm
1800 rpm
2100 rpm

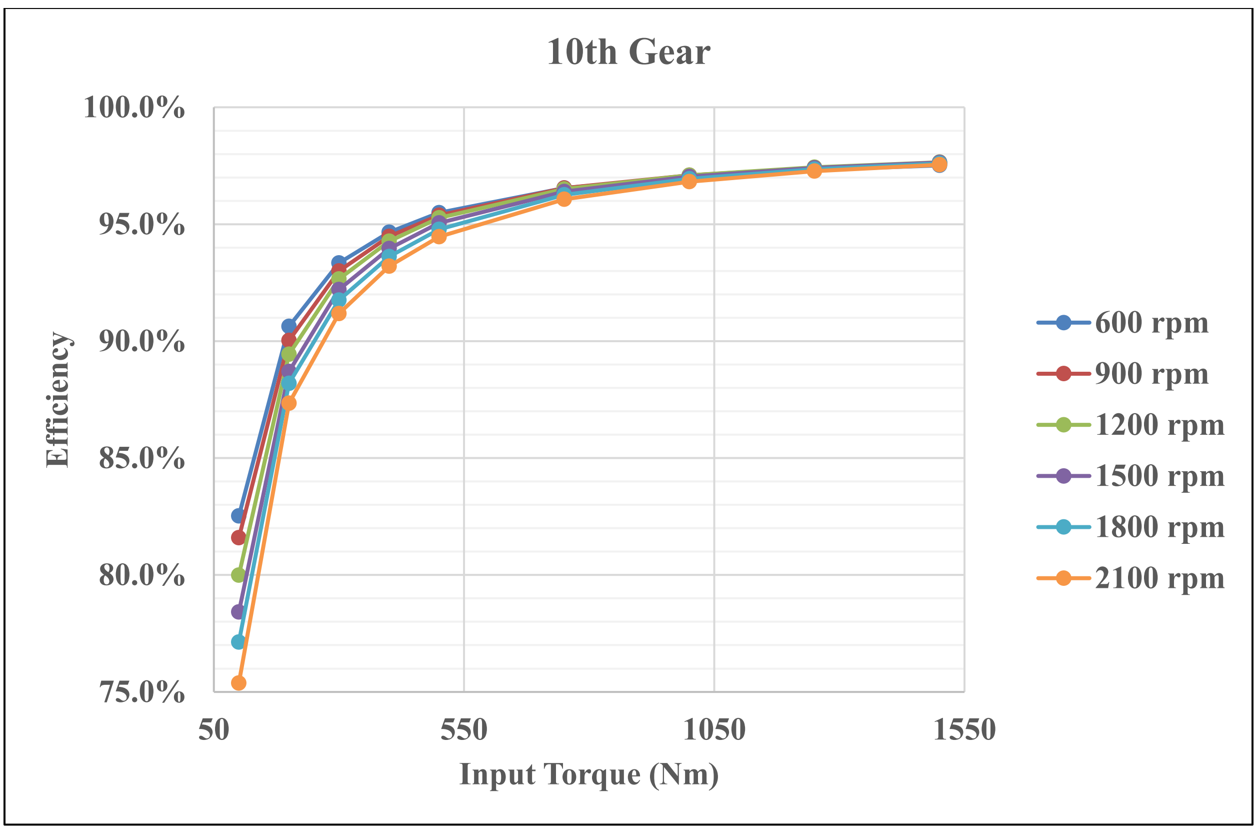

5th Gear
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
Efficiency
50
150
250
350
450
550
650
750
850
Input Torque (Nm)
600 rpm
900 rpm
1200 rpm
1500 rpm
1800 rpm
2100 rpm

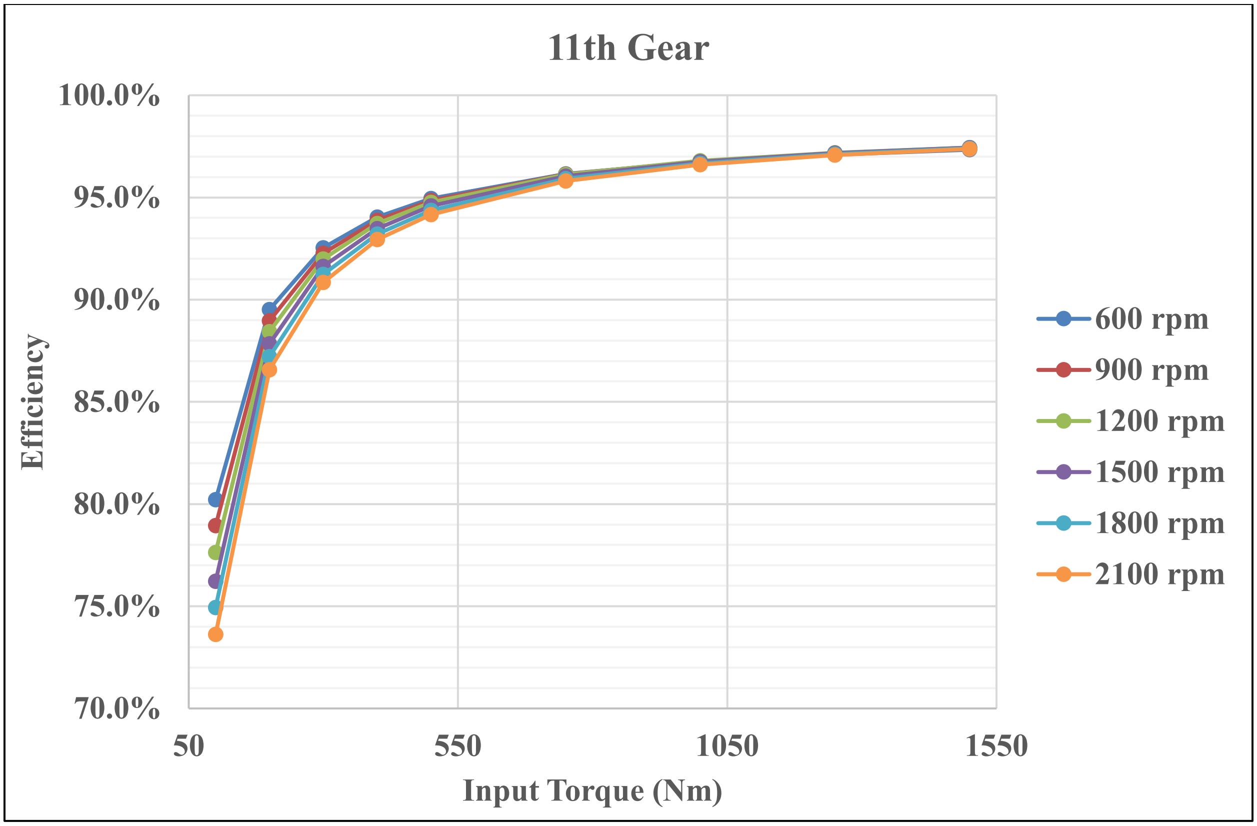

6th Gear
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
Efficiency
50
250
450
650
850
1050
Input Torque (Nm)
600 rpm
900 rpm
1200 rpm
1500 rpm
1800 rpm
2100 rpm

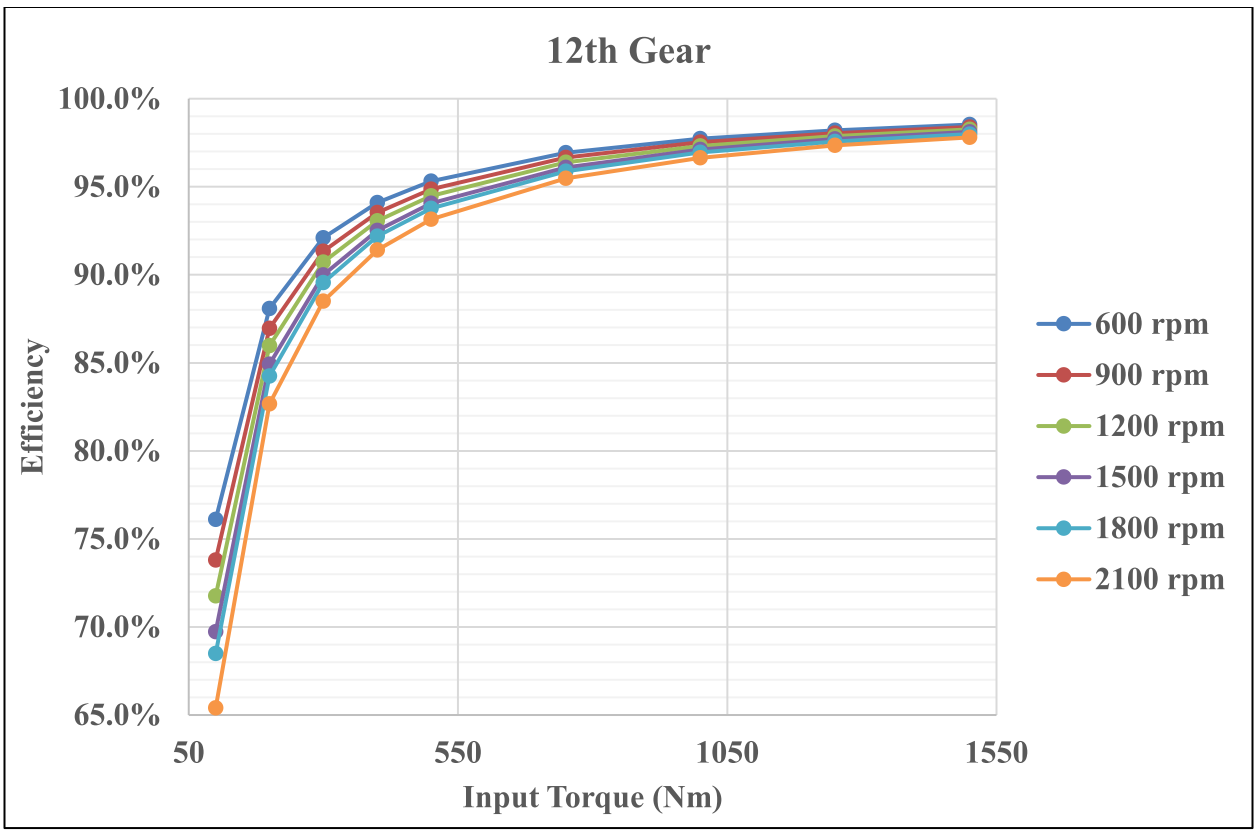

7th Gear
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
Efficiency
50
250
450
650
850
1050
Input Torque (Nm)
600 rpm
900 rpm
1200 rpm
1500 rpm
1800 rpm
2100 rpm


8th Gear
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
Efficiency
50
250
450
650
850
1050
Input Torque (Nm)
600 rpm
900 rpm
1200 rpm
1500 rpm
1800 rpm
2100 rpm


9th Gear
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
Efficiency
50
250
450
650
850
1050
1250
1450
Input Torque (Nm)
600 rpm
900 rpm
1200 rpm
1500 rpm
1800 rpm
2100 rpm


10th Gear
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
Efficiency
50
550
1050
1550
Input Torque (Nm)
600 rpm
900 rpm
1200 rpm
1500 rpm
1800 rpm
2100 rpm


11th Gear
Efficiency
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
70.0%
50
550
1050
1550
Input Torque (Nm)
600 rpm
900 rpm
1200 rpm
1500 rpm
1800 rpm
2100 rpm


12th Gear
Efficiency
100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
70.0%
65.0%
50
550
1050
1550
Input Torque (Nm)
600 rpm
900 rpm
1200 rpm
1500 rpm
1800 rpm
2100 rpm

Appendix B: Volvo I-Shift Component Inertia: Volvo I-Shift Inertia Data

80°C									
Gear	**Acceleration Ramp Torque**				**Steady-State Torque**			**Inertia Calculations**	
1	Speed (rpm)	Temp (°C)	Acceleration (rad/s^2)	Torque (Nm)	Speed (rpm)	Temp (°C)	Torque (Nm)	Accel Torque (Nm)	Inertia (kgm^2)
600	611.61	79.45	3.48	6.25	599.99	79.31	3.72	2.53	0.73
900	899.74	79.42	4.45	7.53	899.65	79.33	4.91	2.62	0.59
1,200	1,200.34	79.23	4.45	8.50	1,200.01	79.39	5.97	2.53	0.57
1,500	1,499.48	79.14	4.44	9.44	1,499.44	79.59	6.80	2.64	0.59
1,800	1,799.27	78.85	4.45	10.34	1,799.43	79.69	7.67	2.67	0.60
2,100					2,099.89	79.96	8.50		

Gear	**Acceleration Ramp Torque**				**Steady-State Torque**			**Inertia Calculations**	
2	Speed (rpm)	Temp (°C)	Acceleration (rad/s^2)	Torque (Nm)	Speed (rpm)	Temp (°C)	Torque (Nm)	Accel Torque (Nm)	Inertia (kgm^2)
600	611.34	78.89	3.20	7.63	600.12	79.60	4.83	2.80	0.88
900	900.04	78.81	4.50	9.52	900.00	79.57	6.56	2.96	0.66
1,200	1,199.80	78.71	4.42	10.68	1,199.98	79.77	7.84	2.84	0.64
1,500	1,500.09	78.54	4.44	11.75	1,500.01	79.84	9.18	2.57	0.58
1,800	1,799.43	78.37	4.43	13.24	1,799.65	80.06	10.45	2.79	0.63
2,100	2,090.16	78.23	2.78	14.68	2,099.88	80.14	11.92	2.76	0.99

Gear	**Acceleration Ramp Torque**				**Steady-State Torque**			**Inertia Calculations**	
3	Speed (rpm)	Temp (°C)	Acceleration (rad/s^2)	Torque (Nm)	Speed (rpm)	Temp (°C)	Torque (Nm)	Accel Torque (Nm)	Inertia (kgm^2)
600	611.15	79.22	3.30	6.60	600.01	79.44	4.18	2.41	0.73
900	899.76	79.17	4.46	8.17	899.73	79.14	5.48	2.69	0.60
1,200	1,199.82	78.94	4.43	9.29	1,200.01	79.30	6.53	2.75	0.62
1,500	1,500.06	78.84	4.42	10.33	1,499.72	79.31	7.55	2.78	0.63
1,800	1,799.39	78.71	4.46	11.35	1,799.78	79.59	8.55	2.80	0.63
2,000					2,099.94	79.91	9.54		

Gear	Acceleration Ramp Torque				Steady-State Torque			Inertia Calculations	
4	Speed (rpm)	Temp (°C)	Acceleration (rad/s^2)	Torque (Nm)	Speed (rpm)	Temp (°C)	Torque (Nm)	Accel Torque (Nm)	Inertia (kgm^2)
600	611.24	79.12	3.29	8.34	600.22	78.73	5.58	2.76	0.84
900	899.72	79.04	4.48	10.28	899.59	78.78	7.22	3.06	0.68
1,200	1,199.69	78.84	4.45	11.78	1,199.80	78.77	8.69	3.10	0.70
1,500	1,499.55	78.71	4.40	13.43	1,499.48	79.05	10.31	3.12	0.71
1,800	1,799.62	78.49	4.46	15.01	1,799.63	79.46	11.80	3.20	0.72
2,100					2,099.91	79.94	13.48		

Gear	Acceleration Ramp Torque				Steady-State Torque			Inertia Calculations	
5	Speed (rpm)	Temp (°C)	Acceleration (rad/s^2)	Torque (Nm)	Speed (rpm)	Temp (°C)	Torque (Nm)	Accel Torque (Nm)	Inertia (kgm^2)
600	611.23	79.02	3.27	7.67	599.93	79.41	3.72	3.95	1.21
900	900.17	78.87	4.45	9.59	899.83	79.42	4.93	4.66	1.05
1,200	1,199.91	78.67	4.45	11.03	1,199.72	79.55	6.05	4.97	1.12
1,500	1,500.13	78.54	4.43	12.20	1,499.93	79.83	6.95	5.25	1.19
1,800	1,799.58	78.51	4.45	13.63	1,799.84	80.03	7.81	5.82	1.31
2,100					2,099.96	79.90	8.82		

Gear	Acceleration Ramp Torque				Steady-State Torque			Inertia Calculations	
6	Speed (rpm)	Temp (°C)	Acceleration (rad/s^2)	Torque (Nm)	Speed (rpm)	Temp (°C)	Torque (Nm)	Accel Torque (Nm)	Inertia (kgm^2)
600	614.63	78.86	3.83	10.25	600.06	79.00	4.90	5.35	1.40
900	899.93	78.69	4.46	12.43	900.12	79.02	6.61	5.82	1.31
1,200	1,200.42	78.54	4.47	14.41	1,200.34	79.26	7.90	6.51	1.46
1,500	1,500.04	78.45	4.46	16.67	1,499.81	79.65	9.13	7.54	1.69
1,800	1,799.86	78.29	4.45	18.87	1,799.87	80.09	10.51	8.35	1.88
2,100					2,100.01	80.06	12.12		

Gear	Acceleration Ramp Torque				Steady-State Torque			Inertia Calculations	
7	Speed (rpm)	Temp (°C)	Acceleration (rad/s^2)	Torque (Nm)	Speed (rpm)	Temp (°C)	Torque (Nm)	Accel Torque (Nm)	Inertia (kgm^2)
600	611.41	79.63	3.23	6.39	600.05	79.19	3.91	2.48	0.77
900	900.12	79.50	4.45	7.77	900.06	79.05	5.10	2.67	0.60
1,200	1,200.12	79.31	4.45	8.97	1,199.81	79.15	6.20	2.76	0.62
1,500	1,499.89	79.17	4.45	9.82	1,499.97	79.31	7.05	2.77	0.62
1,800	1,800.06	78.90	4.49	10.75	1,799.80	79.35	7.96	2.79	0.62
2,100					2,100.31	79.85	8.81		

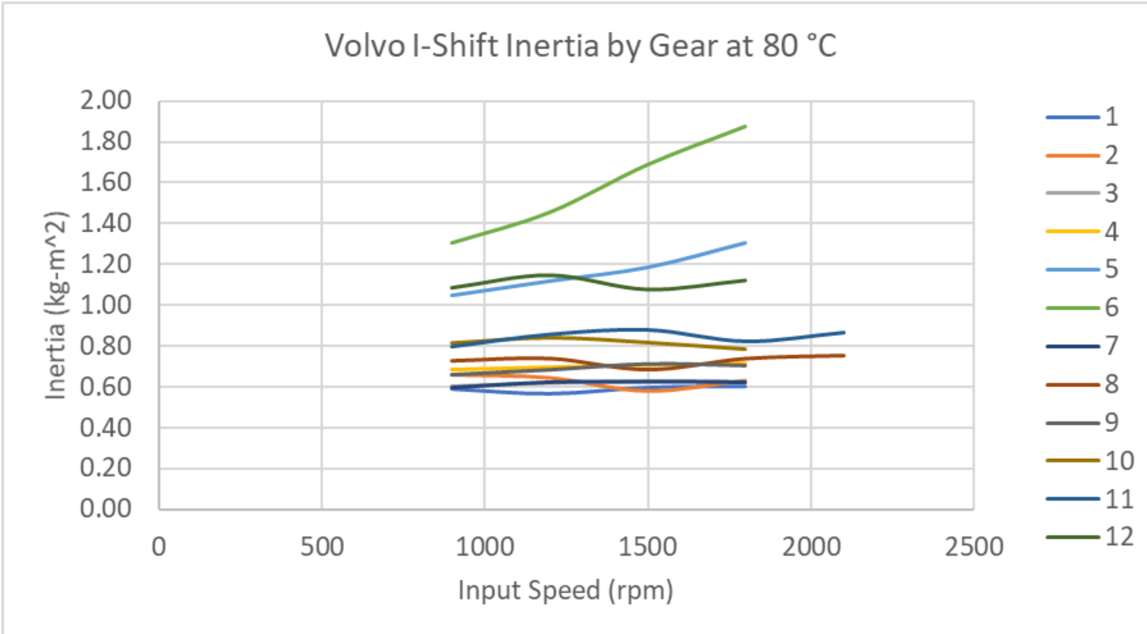
Gear	Acceleration Ramp Torque				Steady-State Torque			Inertia Calculations	
8	Speed (rpm)	Temp (°C)	Acceleration (rad/s^2)	Torque (Nm)	Speed (rpm)	Temp (°C)	Torque (Nm)	Accel Torque (Nm)	Inertia (kgm^2)
600	612.71	79.18	3.61	8.05	600.10	79.40	4.98	3.07	0.85
900	899.61	79.19	4.45	9.91	899.88	79.43	6.67	3.24	0.73
1,200	1,200.38	79.05	4.43	11.24	1,200.10	79.51	7.96	3.27	0.74
1,500	1,499.99	78.86	4.39	12.30	1,499.97	79.69	9.31	2.99	0.68
1,800	1,787.60	78.62	4.44	14.00	1,799.13	79.96	10.72	3.29	0.74
2,100	2,082.57	78.39	4.19	15.43	2,099.88	80.00	12.26	3.17	0.76

Gear	Acceleration Ramp Torque				Steady-State Torque			Inertia Calculations	
9	Speed (rpm)	Temp (°C)	Acceleration (rad/s^2)	Torque (Nm)	Speed (rpm)	Temp (°C)	Torque (Nm)	Accel Torque (Nm)	Inertia (kgm^2)
600	610.78	79.35	3.23	7.00	600.07	79.24	4.37	2.63	0.81
900	900.29	79.06	4.45	8.57	900.45	79.10	5.63	2.94	0.66
1,200	1,200.06	79.11	4.47	9.75	1,200.05	79.05	6.68	3.06	0.68
1,500	1,499.19	79.10	4.44	10.90	1,499.47	79.06	7.73	3.17	0.71
1,800	1,799.85	78.78	4.48	11.91	1,799.59	79.37	8.75	3.16	0.71
2,100					2,100.13	79.75	9.76		

Gear	Acceleration Ramp Torque				Steady-State Torque			Inertia Calculations	
10	Speed (rpm)	Temp (°C)	Acceleration (rad/s^2)	Torque (Nm)	Speed (rpm)	Temp (°C)	Torque (Nm)	Accel Torque (Nm)	Inertia (kgm^2)
600	609.79	79.09	2.70	8.74	600.06	79.24	5.75	3.00	1.11
900	900.05	79.07	4.47	11.08	899.88	79.21	7.45	3.64	0.81
1,200	1,199.73	79.02	4.48	12.63	1,199.93	79.27	8.88	3.76	0.84
1,500	1,499.78	78.73	4.42	14.12	1,499.60	79.43	10.51	3.61	0.82
1,800	1,799.90	78.46	4.46	15.51	1,799.92	79.77	12.00	3.50	0.79
2,100	2,084.97	78.28	4.00	17.55	2,099.81	80.12	13.59	3.96	0.99

Gear	Acceleration Ramp Torque				Steady-State Torque			Inertia Calculations	
11	Speed (rpm)	Temp (°C)	Acceleration (rad/s^2)	Torque (Nm)	Speed (rpm)	Temp (°C)	Torque (Nm)	Accel Torque (Nm)	Inertia (kgm^2)
600	613.79	79.31	3.92	8.89	600.08	78.75	5.40	3.49	0.89
900	900.15	79.04	4.44	10.46	899.93	78.45	6.91	3.55	0.80
1,200	1,199.73	78.74	4.48	12.04	1,199.86	78.30	8.21	3.84	0.86
1,500	1,499.96	78.93	4.45	13.36	1,500.12	78.41	9.46	3.90	0.88
1,800	1,799.48	78.50	4.48	14.42	1,799.52	78.81	10.73	3.69	0.82
2,100	2,082.22	78.32	4.42	15.64	2,100.34	79.28	11.82	3.82	0.86

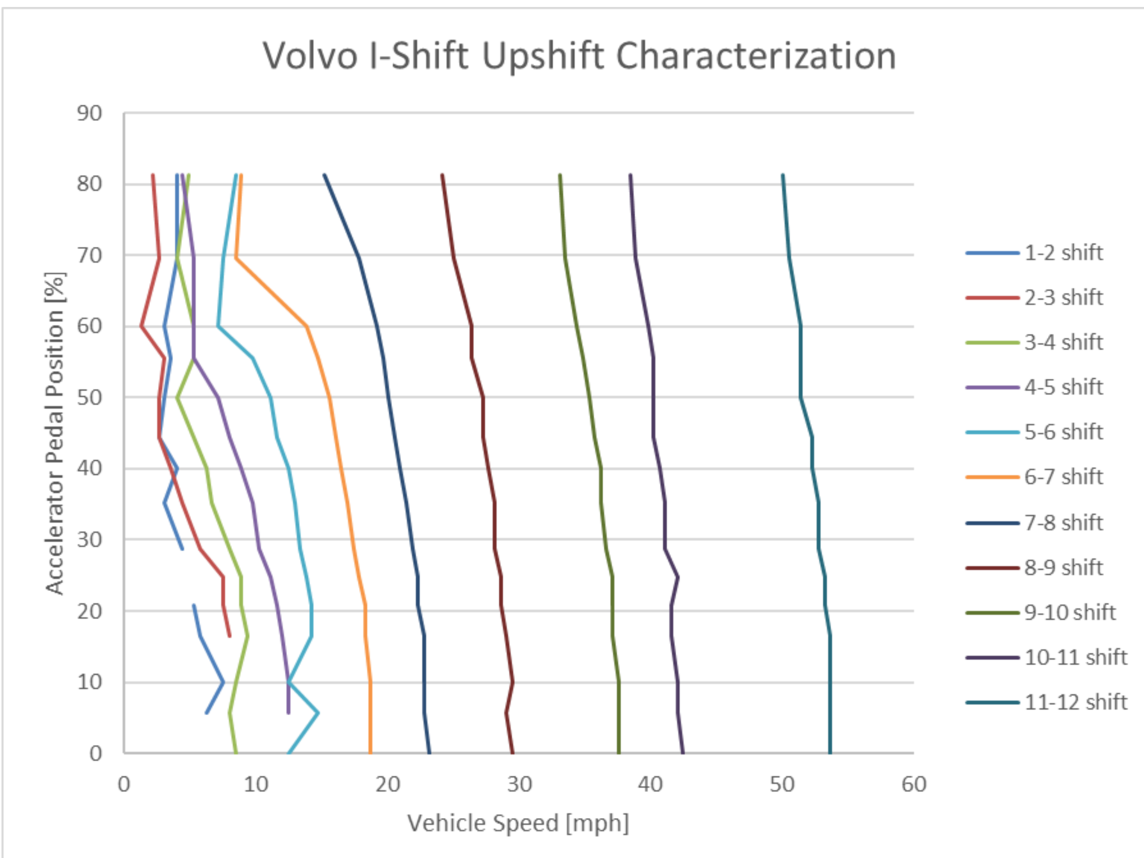
Gear	Acceleration Ramp Torque				Steady-State Torque			Inertia Calculations	
12	Speed (rpm)	Temp (°C)	Acceleration (rad/s^2)	Torque (Nm)	Speed (rpm)	Temp (°C)	Torque (Nm)	Accel Torque (Nm)	Inertia (kgm^2)
600	616.81	78.49	4.19	11.81	599.94	79.63	7.03	4.78	1.14
900	900.24	78.55	4.44	13.99	900.13	79.51	9.16	4.82	1.09
1,200	1,199.55	78.45	4.45	16.11	1,199.72	79.60	11.01	5.10	1.15
1,500	1,499.88	78.07	4.41	17.79	1,499.89	79.96	13.04	4.76	1.08
1,800	1,787.91	77.79	4.49	20.04	1,799.74	80.16	15.00	5.04	1.12
2,100					2,100.34	80.27	17.10		



Volvo I-Shift Inertia by Gear at 80 °C
Inertia (kg-m^2)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
500
1000
1500
2000
2500
Input Speed (rpm)
1
2
3
4
5
6
7
8
9
10
11
12

Appendix C: Volvo I-Shift In-Use: Volvo I-Shift – Upshift and Downshift Characterizations

Upshift Speeds (mph)															
	Accel Position (%)														
Gear	0	5.6	10	16.4	20.8	24.8	28.8	35.2	40	44.4	50	55.6	60	69.6	81.2
2		6.3	7.6	5.8	5.4		4.5	3.1	4.0	2.7	3.1	3.6	3.1	4.0	4.0
3		8.1		8.1	7.6	7.6	5.8	4.5	3.6	2.7	2.7	3.1	1.3	2.7	2.2
4	8.5	8.1	8.5	9.4	8.9	8.9	8.1	6.7	6.3	5.4	4.0	5.4	5.4	4.0	4.9
5		12.5	12.5	12.1	11.6	11.2	10.3	9.8	8.9	8.1	7.2	5.4	5.4	5.4	4.5
6	12.5	14.8	12.5	14.3	14.3	13.9	13.4	13.0	12.5	11.6	11.2	9.8	7.2	7.6	8.5
7	18.8	18.8	18.8	18.3	18.3	17.9	17.4	17.0	16.6	16.1	15.7	14.8	13.9	8.5	8.9
8	23.3	22.8	22.8	22.8	22.4	22.4	21.9	21.5	21.0	20.6	20.1	19.7	19.2	17.9	15.2
9	29.5	29.1	29.5	29.1	28.6	28.6	28.2	28.2	27.7	27.3	27.3	26.4	26.4	25.1	24.2
10	37.6	37.6	37.6	37.1	37.1	37.1	36.7	36.2	36.2	35.8	35.3	34.9	34.4	33.6	33.1
11	42.5	42.1	42.1	41.6	41.6	42.1	41.2	41.2	40.7	40.3	40.3	40.3	39.8	38.9	38.5
12	53.7	53.7	53.7	53.7	53.2	53.2	52.8	52.8	52.3	52.3	51.4	51.4	51.4	50.6	50.1



Downshift Speeds (mph)															
	Accel Position (%)														
Gear	0	5.6	10	16	21	25	29	35	40	45	50	55	60	70	81
10	35.8	35.8	35.8	35.3	35.3	35.3	35.3	34.9	34.9	34.9	34.4	34.4	34.4	34.4	34.4
8	21.9	21.9	21.9	21.5	21.5	21.0	21.0	20.6	20.6	20.6	20.1	20.1	20.1	20.1	20.1
6	13.4	13.0	13.0	13.0	12.5		11.6	11.2	10.7	11.2	10.3	10.7	10.3	10.7	10.7
5						12.1								6.7	6.3
4	8.1	8.1	8.1	7.6	7.2		5.8	4.9	4.9	5.4					
3														4.9	
2	4.9	4.5	4.5	4.0	3.1		0.9								
1	3.1	2.7	2.2	1.8	0.4	4.0	1.3								

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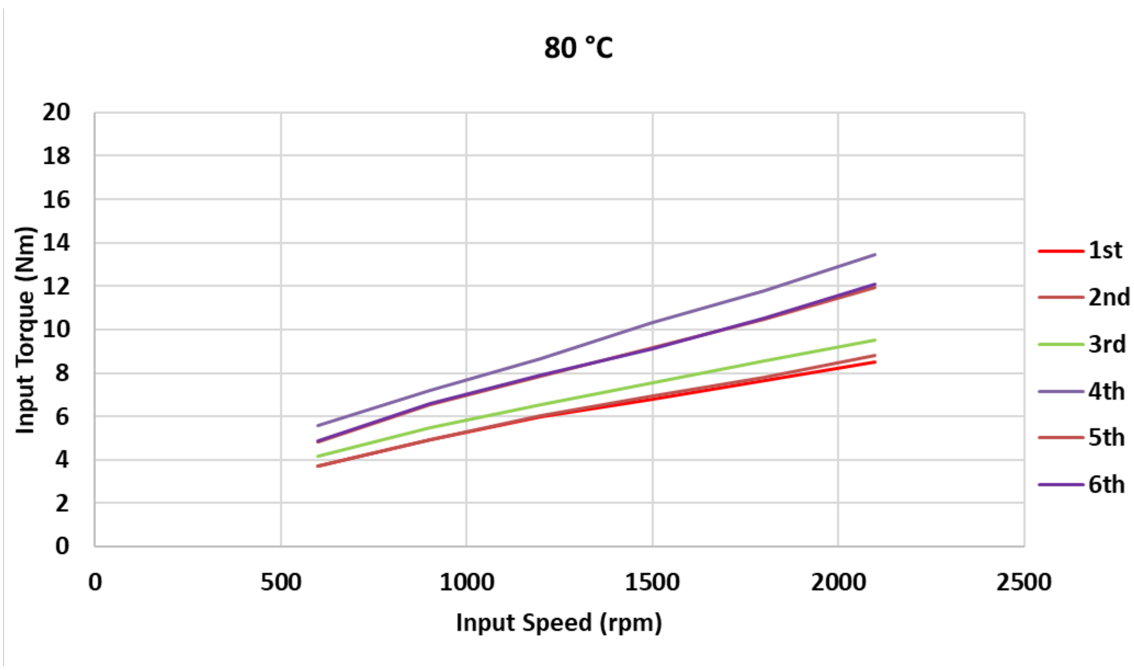
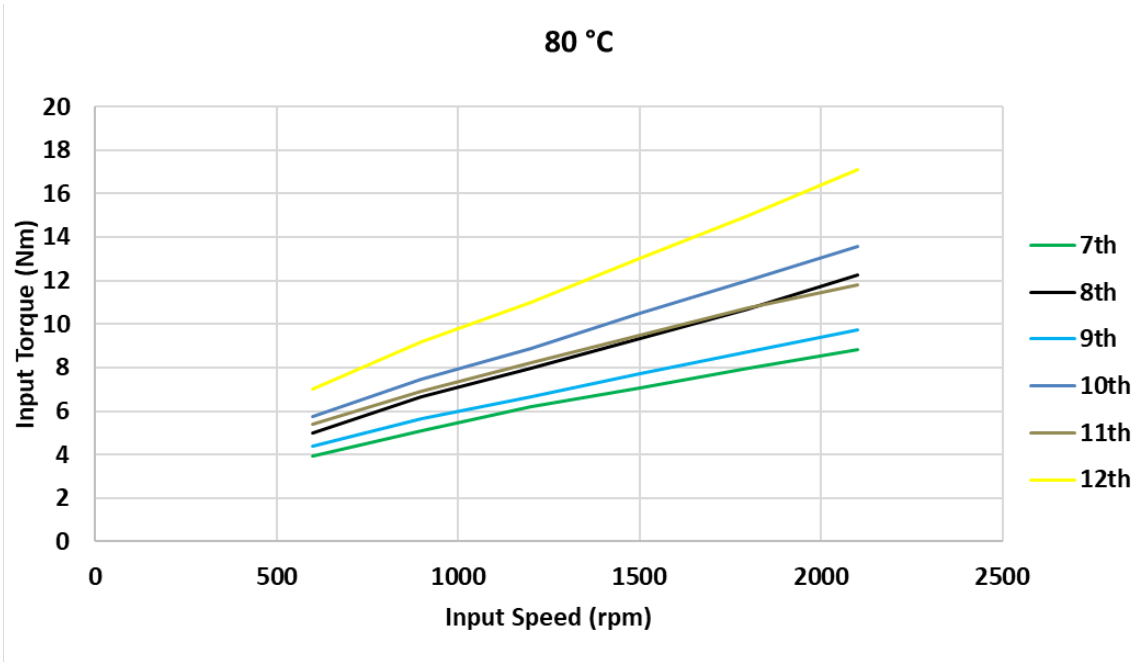
Appendix D: Volvo I-Shift Spinloss Data (Nm)

80°C		Gear					
		1	2	3	4	5	6
Input Speed (rpm)	600	3.72	4.83	4.18	5.58	3.72	4.90
	900	4.91	6.56	5.48	7.22	4.93	6.61
	1,200	5.97	7.84	6.53	8.69	6.05	7.90
	1,500	6.80	9.18	7.55	10.31	6.95	9.13
	1,800	7.67	10.45	8.55	11.80	7.81	10.51
	2,100	8.50	11.92	9.54	13.48	8.82	12.12
		Gear					
		7	8	9	10	11	12
Input Speed (rpm)	600	3.91	4.98	4.37	5.75	5.40	7.03
	900	5.10	6.67	5.63	7.45	6.91	9.16
	1,200	6.20	7.96	6.68	8.88	8.21	11.01
	1,500	7.05	9.31	7.73	10.51	9.46	13.04
	1,800	7.96	10.72	8.75	12.00	10.73	15.00
	2,100	8.81	12.26	9.76	13.59	11.82	17.10




80 °C
Input Torque (Nm)
20
18
16
14
12
10
8
6
4
2
0
0
500
1000
1500
2000
2500
Input Speed (rpm)
7th
8th
9th
10th
11th
12th

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