



U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

Memorandum

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**INFORMATION Redacted PURSUANT TO THE FREEDOM OF
INFORMATION ACT (FOIA), 5 U.S.C. 552(B)(6)**

Subject: FINAL REPORT: PE10-008 "2009-2010 Toyota Corolla
Electric Power Steering"

Date:

From: Roger A. Saul *Rog A Saul*
Director
Vehicle Research and Test Center

Reply to: NVS-310
Attn. Of:

To: Frank Borris
Director
Office of Defects Investigation

Attached is a pdf of the final report in titled "2009-2010 Toyota Corolla Electric Power Steering." This report completes the requirements for this program.

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Memorandum Report
PE10-008
Toyota Corolla Electric Power Steering

Background

Beginning with the 2009 model year, and continuing into the 2010 model year, the Toyota Corolla has been equipped with electric power steering (EPS). This system uses an electric motor for power steering assist in place of the previously utilized hydraulic power steering system. Soon after the 2009 model was released for sale, the National Highway Traffic Safety Administration (NHTSA) began receiving complaints from consumers claiming to have safety issues that related to the EPS. Some complainants stated that they found it fatiguing to drive their Corolla at highway speeds for longer periods of time because of the constant attention that was required to keep the vehicle within the driving lane. Other complainants stated that any inattention to their driving, such as tuning the radio or adjusting the heat/air conditioning caused the vehicle to veer from the intended direction of travel.

In addition to the owner complaints that were received by NHTSA, owner complaints were also reportedly submitted to the manufacturer. In response, Toyota issued a Technical Service Bulletin (TSB) (T-SB-0140-10) that provided a repair procedure for consumers expressing dissatisfaction with on-center steering feel on the model year 2009 and 2010 Corolla vehicles. The TSB instructed dealer technicians to verify the customer's concern; verify proper tire inflation pressures; determine if steering pull was present and diagnose and repair the condition if present; check tires for irregular wear that may indicate an alignment concern (replacing, as necessary, tires showing excessive wear); and check suspension components for damage or irregular wear. If the above conditions were NOT present, dealers were instructed to replace the Power Steering Electronic Control Unit (ECU) with a re-tuned ECU that Toyota had developed to provide an alternative steering feel for these customers.

The Vehicle Research and Test Center (VRTC) was asked to evaluate the replacement ECU, compare the operating characteristics of the original and replacement ECUs, and to ensure that the new ECU did not degrade the controllability of the vehicle.

Test Vehicle As Received

A 2010 Corolla S (VIN: 1NXBU4EE2AZ[REDACTED]) was purchased from a VOQ owner for testing. At the time of purchase, the odometer registered slightly in excess of 11,000 miles. The vehicle was in like-new condition. After taking delivery of the vehicle at the owner's residence, the vehicle was driven approximately 80 miles to VRTC with much of the trip being on interstate highways at 65 mph. The steering was found to be very precise with virtually no free play in the steering. Even the slightest movement of the steering wheel caused the vehicle to change direction. Additionally, the effort that was required to slightly adjust the steering wheel in order to maintain a straight direction of travel was somewhat high. The combination of increased steering effort and the lack of play in the steering system called for a very delicate touch on the steering wheel.

The receiving inspection at VRTC showed that the vehicle was equipped with original equipment Goodyear 205/55R15 RSA tires. Toyota's recommended tire pressure for these tires is 32 psi. Goodyear's maximum allowable inflation pressure is 51 psi. The tire pressures were found to have been adjusted to 38 psi by the previous owner¹. After allowing the tires to cool overnight, the inflation pressure in all four tires was adjusted to the recommended 32 psi. Subjectively, reducing the tire pressures to the manufacturer's recommended level caused the vehicle to be less sensitive to steering wheel inputs and generally somewhat easier to operate. All subsequent tests were performed at the recommended 32 psi.

Objective Testing

Since the power steering assist that is provided to the driver is directly proportional to the EPS motor current, a Techstream² computer was connected to the vehicle's OBD port to monitor steering wheel torque and EPS motor current. Upon request, the part number for the ECU that is utilized in Toyota's TSB was provided by Toyota. An ECU was then purchased from a local Toyota dealership and attached to the test vehicle such that the vehicle's electrical connections could easily and quickly be switched between the original and the replacement ECUs. With the

¹ A 2010 Corolla LE Limited that is owned by VRTC is equipped with original equipment Goodyear 195/65R15 Eagle LS₂ tires. The recommended and maximum tire pressures on this vehicle are 30 and 51 psi, respectively.

² Techstream is the factory-authorized electronic interface tool used by Toyota dealership service departments to electronically analyze all vehicle systems except the event data recorder.

Techstream gathering data at 3.3 Hz,³ tests were performed that compared the performance of the two ECUs. In each scenario, testing of the two ECUs was performed back-to-back to minimize environmental variables on the test results.

Instrumented testing consisted of 1) lock-to-lock steering inputs at five different simulated speeds⁴ with the vehicle stationary; and 2) driving at 65 mph on a straight, limited access 4-lane asphalt roadway. The stationary tests demonstrated how the output of the ECUs changed with speed. The driving tests compared steering inputs between the two ECUs at similar speeds on a given section of roadway.

Subjective Testing

Subjective testing consisted of driving the vehicle on a 6-mile section of 4-lane, limited access highway using drivers who were chosen from VRTC contractor personnel. The screening process for drivers eliminated anyone who claimed to have knowledge of the purpose of the test.⁵ Each driver was given a verbal explanation of what to expect⁶ prior to the test, and a short questionnaire⁷ to fill out at the conclusion of the test.

Since the results of this testing were purely subjective, two attempts were made to reduce any perceived “correct” questionnaire responses by the test participants. 1) In addition to having questions regarding steering, the questionnaire also included questions regarding braking and handling characteristics; and 2) the testing utilized the four scenarios listed below.

Scenario #1	Scenario #2	Scenario #3	Scenario #4
Run #1 – Original ECU	Run #1 – Replacement ECU	Run #1 – Original ECU	Run #1 – Replacement ECU
Run #2 – Replacement ECU	Run #2 – Original ECU	Run #2 – Original ECU	Run #2 – Replacement ECU

³ 3.3 Hz was the maximum rate that the Techstream was able to gather data.

⁴ With the vehicle stationary, a frequency generator was used to inject a signal into the electronic speedometer circuit to simulate moving at various speeds. Tests were done at simulated speeds of 7, 20, 40, 60, & 80 mph.

⁵ Several of the drivers believed that this testing was in support of a different project that was underway at VRTC at the time that had nothing to do with steering issues. These drivers were allowed to participate in this program and were not informed about the true reason for testing.

⁶ A copy of the Explanation to the Driver is provided in Appendix I.

⁷ A copy of the driver’s questionnaire is provided in Appendix II.

Test Results

Objective Testing

The data showed: 1) at any given combination of vehicle speed and steering wheel input torque, the new ECU provided increased motor current, and thus “assist”; and 2) the gain did not increase linearly with speed or torque. For any given steering wheel torque, gain decreased with vehicle speed. For any given speed, gain increased with steering wheel torque. The gain was variable up to approximately 2 to 3 lb-ft, after which it approached being linear up to the maximum provided by the system. The data plots in Figures 1 – 9 below show steering wheel torque vs. motor current for the objective test scenarios described above.

Subjective Testing

At highway speeds, the new ECU provided a subtle reduction in the amount of effort that was required to begin to move the steering wheel. Because less effort was required to correct slight deviations in the vehicle’s trajectory, the car was easier to drive, which made driving more relaxed. Although the objective tests showed a slight increase in gain at all speeds with the new controller, there was no discernable difference in drivability between the two ECUs at slower speeds.

The subjective driver evaluation tests showed:

- All sixteen participants felt that the vehicle was safe to drive and that the steering felt normal.
- Two of the eight test participants who drove with different ECUs noticed a difference between tests. Both of them drove with the original ECU first and then switched to the new ECU.
- The remaining six participants who drove with different ECUs did not notice a difference between the two ECUs.
- One participant claimed to notice a difference in the handling of the vehicle between tests but did not identify a difference in steering effort.
- None of the eight participants who drove with the same ECU for both tests claimed to have noticed a difference between test runs.

- Although no changes were made to anything but the ECU between test runs, three test participants claimed to have noticed a difference in the vehicle's brakes between test runs.

Results of the subjective testing, taken from the driver's surveys, are shown in Table 1.

Table 1
Results of Subjective Testing from Driver's Survey

Toyota Corolla EPS Driver's Survey												
Test No.	Test Series	Veh. Safe	Braking		Handling		Steering			Driven Corolla Before	Personal Vehicle Normally Driven	Comments
			Ability	Different Between Tests	Ability	Different Between Tests	Feel	Different Between Tests	Corolla Compared to Other Cars			
1	1	Yes	Normal	No	Normal	Yes	Normal	Yes	Worse	No	Grand Prix	Was easier to steer in second test
2	2	Yes	Better	Yes	Normal	No	Normal	No	Same	No	Silverado	Cruise control is "funky"
3	3	Yes	Normal	Yes	Normal	No	Normal	No	Same	No	F-150	Brakes not as good on second test
4	1	Yes	Normal	No	Normal	Yes	Normal	No	Same	No	Avenger	
5	4	Yes	Normal	No	Normal	No	Normal	No	Same	No	Fit	Would be harder to control on windy day
6	3	Yes	Normal	No	Normal	No	Normal	No	Same	No	Concorde	
7	4	Yes	Normal	No	Normal	No	Normal	No	Same	No	Grand Am	
8	2	Yes	Below	No	Normal	No	Normal	No	Same	No	Tiburon	Don't like the brakes. Cruise Control has delay in shutting off.
9	1	Yes	Normal	Yes	Normal	No	Normal	Yes	Same	No	Sebring	Harder to use brake in second test Hard to keep straight in wind.
10	2	Yes	Normal	No	Below	No	Below	No	Worse	No	F250	Steering was tight. Wondered if there was alignment issue.
11	3	Yes	Normal	No	Normal	No	Normal	No	Same	No	Fusion	Suspension was a little loose
12	3	Yes	Below	No	Normal	No	Normal	No	Same	No	Accord	
13	1	Yes	Normal	No	Normal	No	Normal	No	Same	No	C1500	No difference
14	4	Yes	Normal	No	Normal	No	Normal	No	Same	No	F150	
15	4	Yes	Normal	No	Better	No	Normal	No	Better	No	Freestyle	Nice handling vehicle
16	2	Yes	Normal	No	Normal	No	Normal	No	Same	No	Elantra	

Series 1 - Original ECU in test 1, new ECU in test 2

Series 2 - New ECU in test 1, original ECU in test 2

Series 3 - Original ECU in both tests

Series 4 - New ECU in both tests

Torque vs. Motor Current at 65 mph

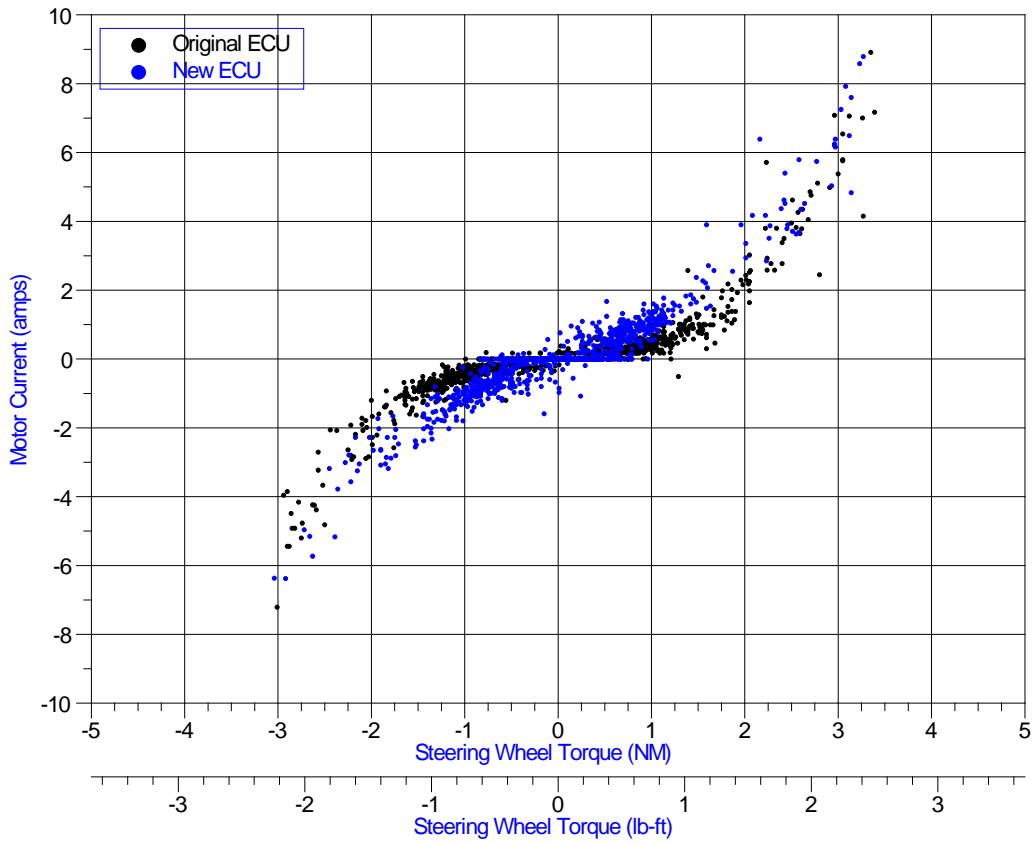


Figure 1
Motor Current vs. Steering Wheel Torque
Steady 65 mph

Original Controller Simulated Speed Testing

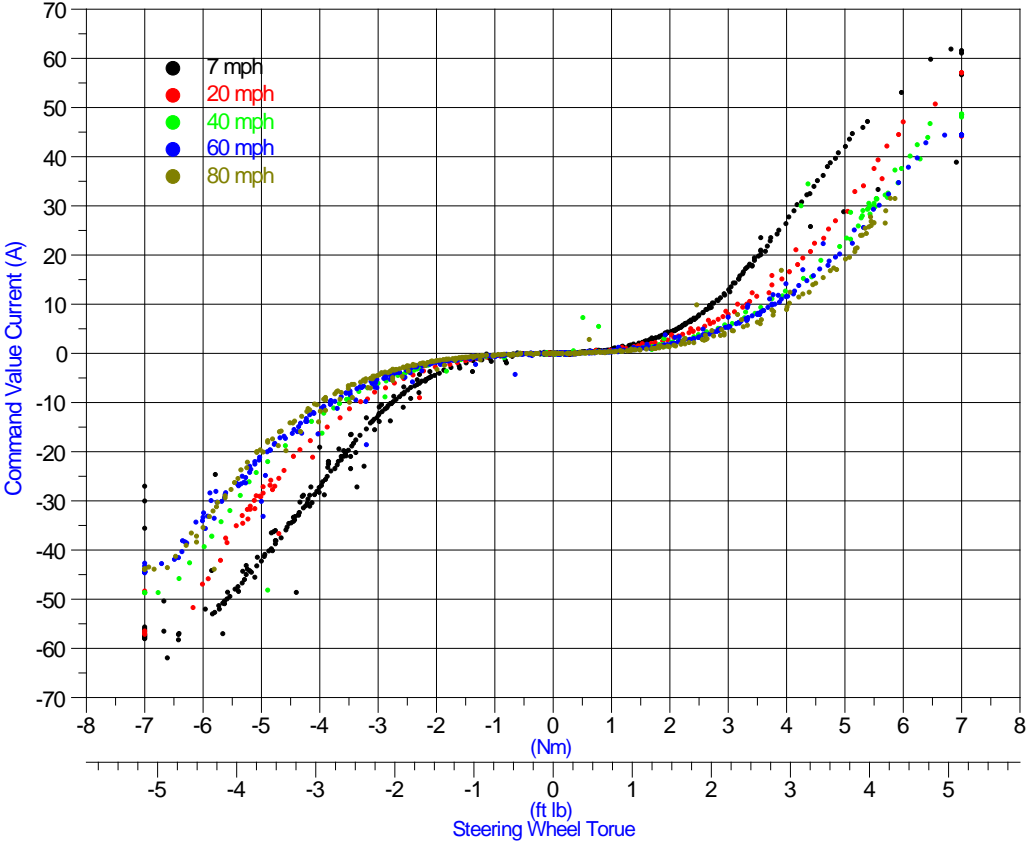


Figure 2
Motor Current vs. Steering Wheel Torque
Comparison of Current at Five Simulated Speeds
Original Controller

New Controller Simulated Speed Testing

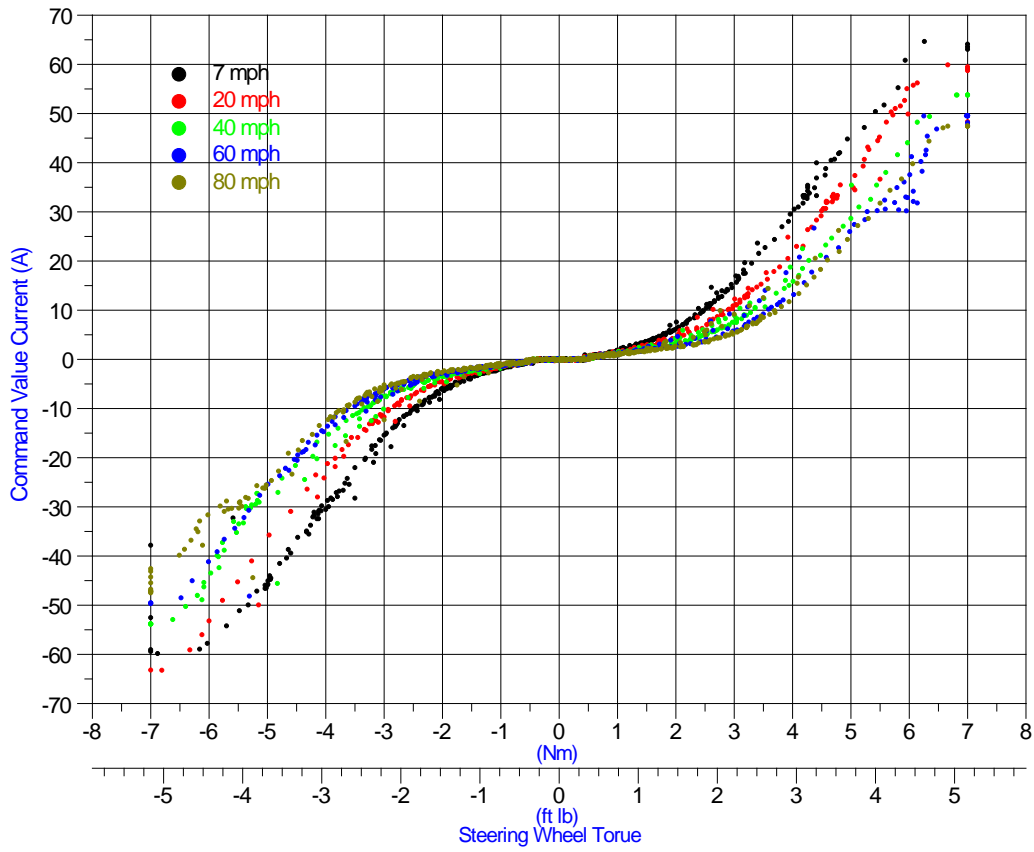


Figure 3
Motor Current vs. Steering Wheel Torque
Comparison of Current at Five Simulated Speeds
New Controller

Torque vs. Motor Current - Vehicle Stationary

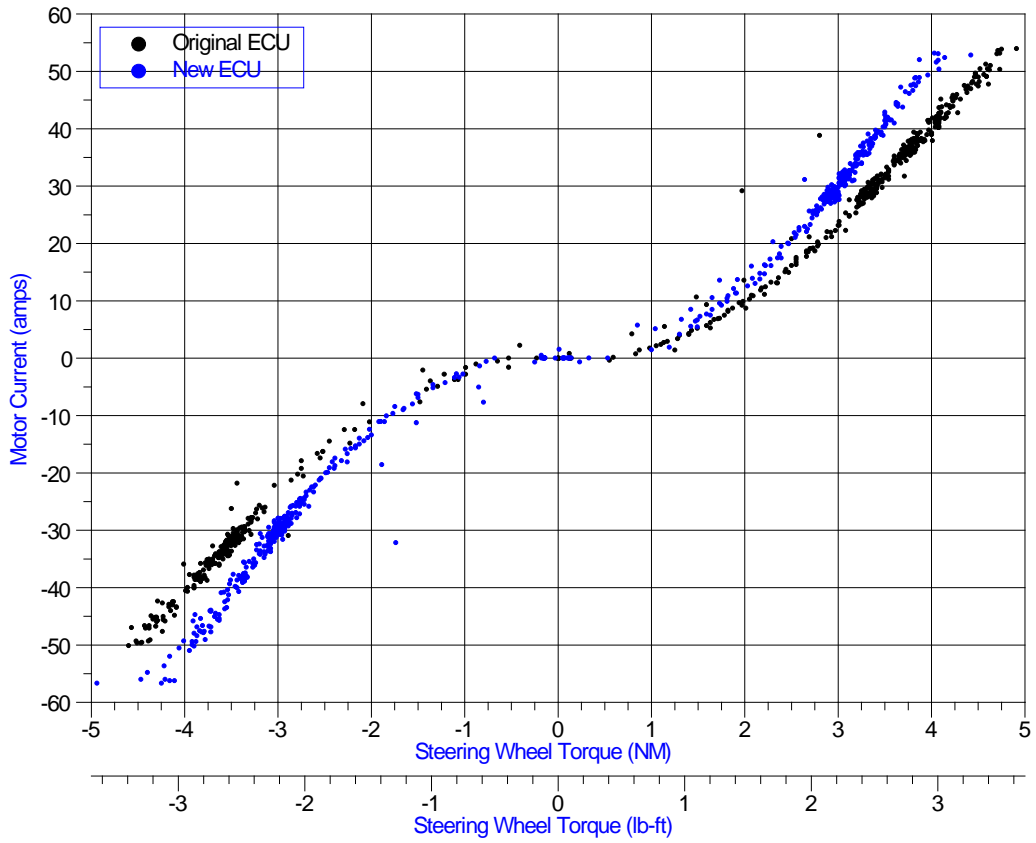


Figure 4
Motor Current vs. Steering Wheel Torque
Vehicle Stationary

Simulated 7 mph Testing

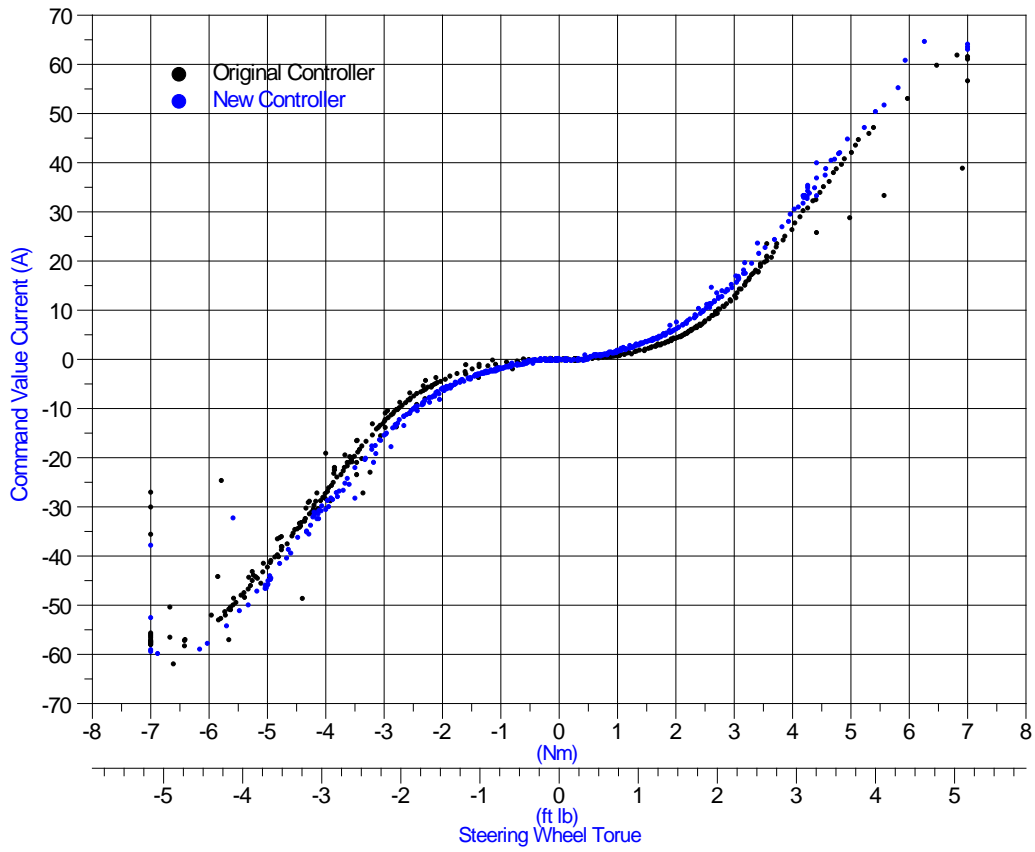


Figure 5
Motor Current vs. Steering Wheel Torque
Simulated 7 mph

Simulated 20 mph Testing

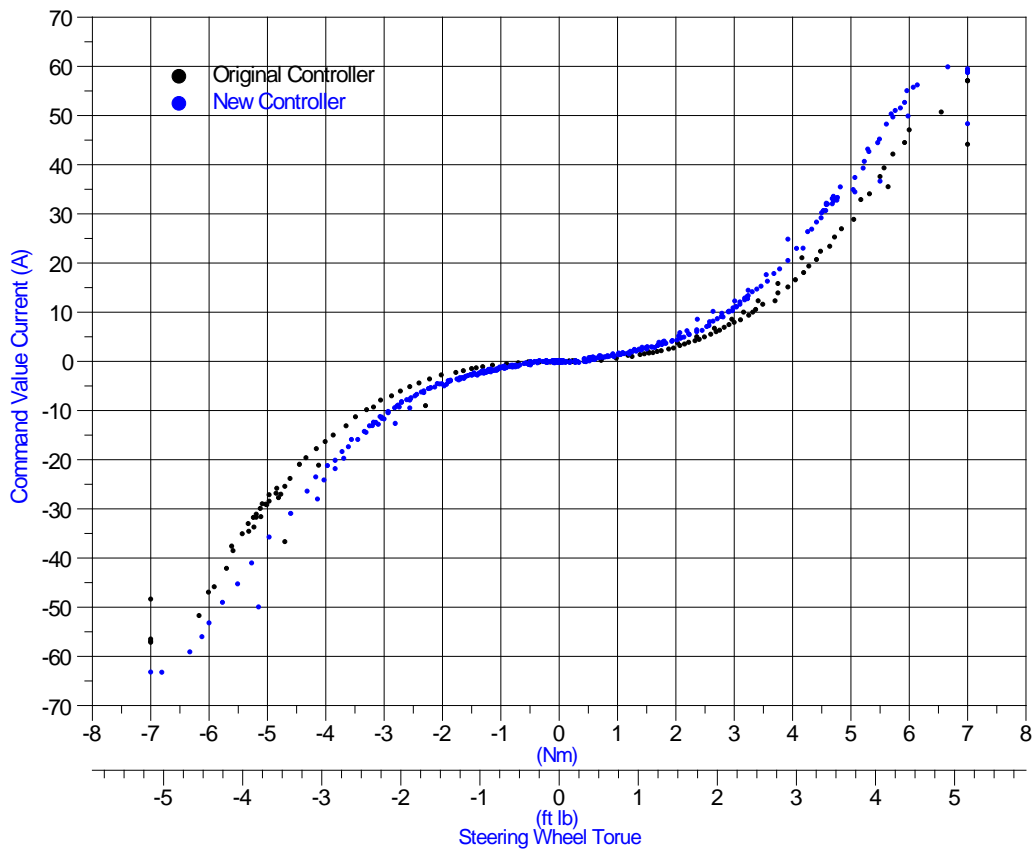


Figure 6
Motor Current vs. Steering Wheel Torque
Simulated 20 mph

Simulated 40 mph Testing

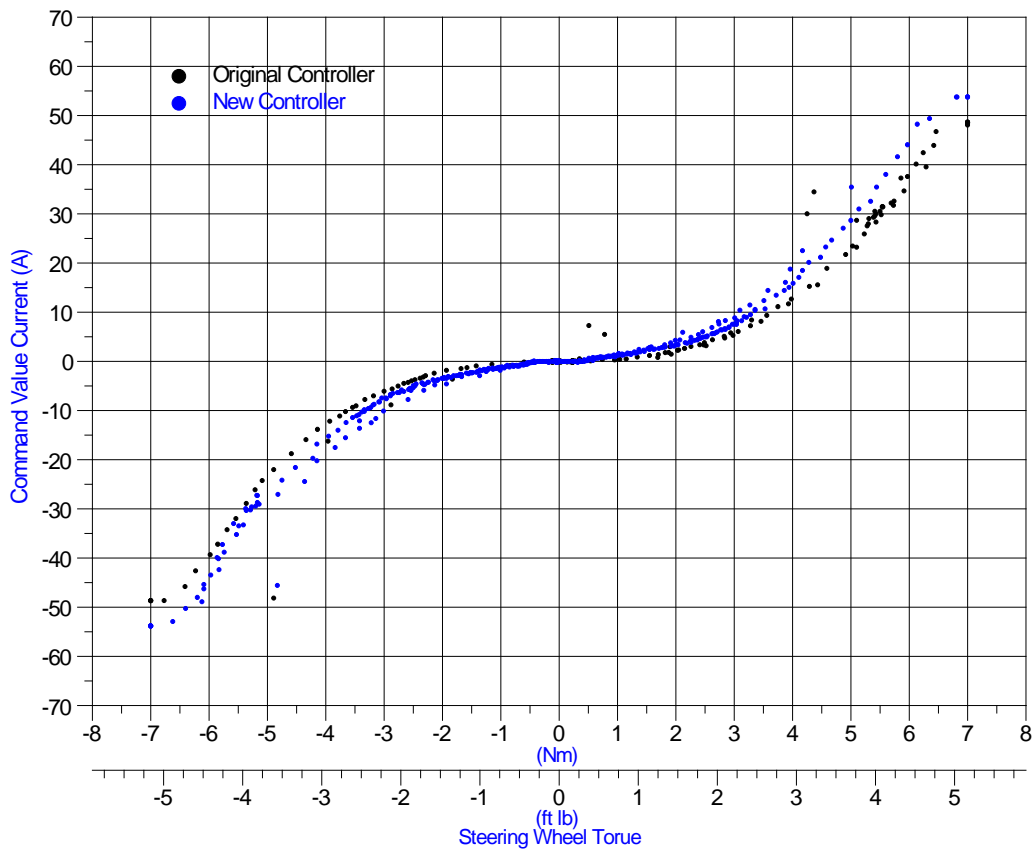


Figure 7
Motor Current vs. Steering Wheel Torque
Simulated 40 mph

Simulated 60 mph Testing

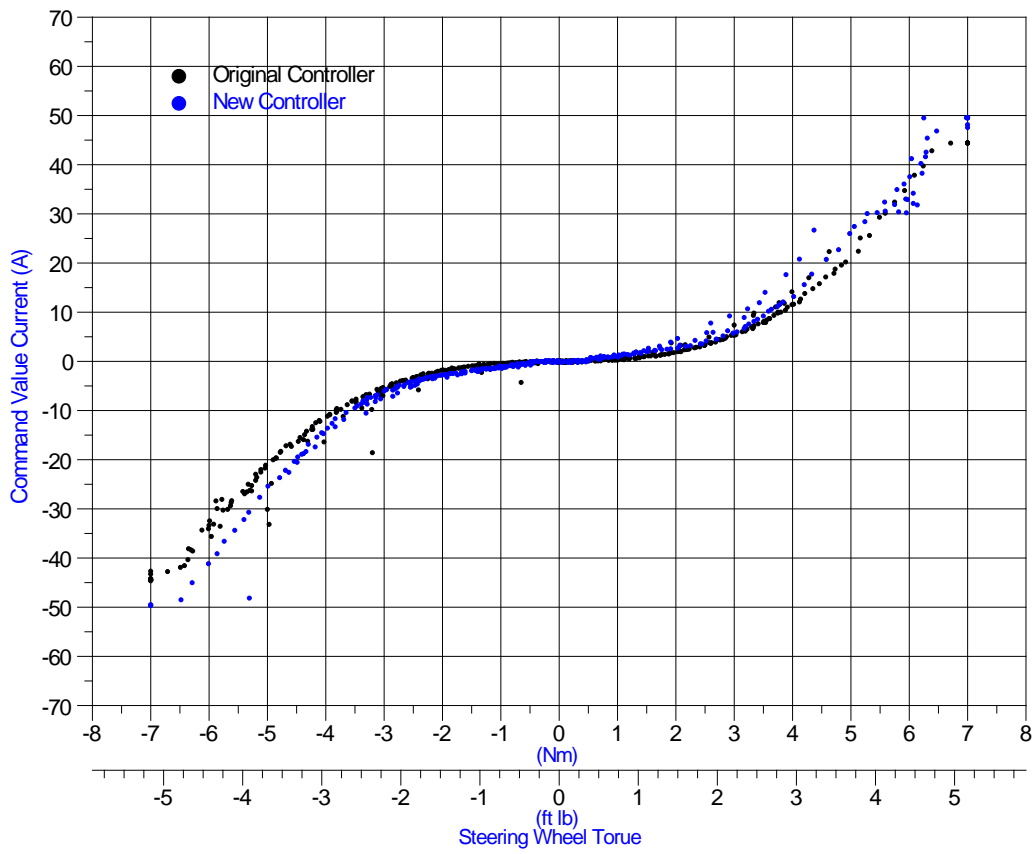


Figure 8
Motor Current vs. Steering Wheel Torque
Simulated 60 mph

Simulated 80 mph Testing

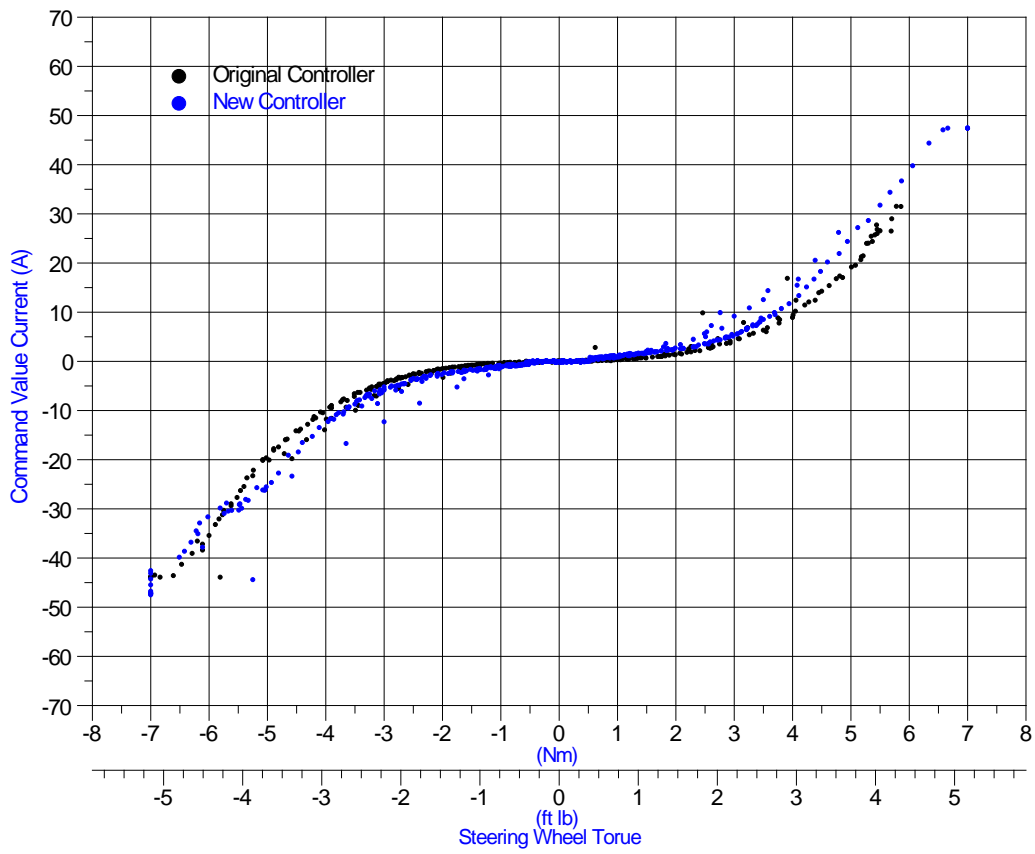


Figure 9
Motor Current vs. Steering Wheel Torque
Simulated 80 mph

Appendix I
Explanation to Driver

Explanation to driver:

This is part of the Toyota unintended acceleration program. The vehicle has been instrumented to monitor various driver control functions. Although most of the instrumentation is hidden, the most obvious is steering wheel input. We ask that you follow instructions and operate the vehicle normally. There will be no surprises along the way. The test should take about one hour. We will be going off property so make sure you have your badge. Feel free to make any comments about the drivability of the vehicle during the test. You will be asked to complete a brief questionnaire at the conclusion of the test.

Appendix II
Questionnaire

Questionnaire

Did you feel that the vehicle was safe to drive? Yes _____ No _____

If no, please explain. _____

How would you classify the braking ability of the car?

Below normal____ Normal_____ Better than normal_____

Did you notice a difference between Test 1 and Test 2? Yes _____ No _____

If so, please describe.

Comments: _____

How would you classify the handling of the car?

Below normal____ Normal _____ Better than normal_____

Did you notice a difference between Test 1 and Test 2? Yes _____ No _____

If so, please describe.

Comments: _____

How would you classify the steering feel of the car?

Below normal____ Normal _____ Better than normal_____

Did you notice a difference between Test 1 and Test 2? Yes _____ No _____

If so, please describe.

Comments: _____

Have you owned, leased, or otherwise driven a Toyota Corolla for an extended period before?

No _____ Yes _____ If yes, how does this Corolla compare?

How would you compare the steering system of the car compared to other cars this size that you have driven?

Better than others_____ Worse than others_____

Same as others_____ No basis for comparison_____

Please list the make, model, and year of your personal vehicle that you drive the most?

Additional comments: _____

Thank you for completing this survey. Please return the completed form to the person who conducted your test.