

Memorandum Report Electric Power Steering Study 2011 Ford Explorer

Background

The Vehicle Research and Test Center (VRTC) was asked to perform an analysis of this vehicle equipped with electric power steering (EPS) for an ongoing study.

Test Vehicle

The test vehicle was a 2011 Ford Explorer Limited (VIN: 1FMHK7F88BG) that was owned by VRTC. Figure 1 shows the test vehicle used for this program.



**Figure 1
Subject Test Vehicle**

Testing

The following areas were addressed for this program.

Vehicle Parameter Measurements

Selected vehicle parameters were measured or calculated. Table 1 lists the items that were measured, calculated, or found in published data. The tire contact area was determined by spreading ink on the front tires, lowering the tires (mounted on the vehicle) onto a piece of paper,

and measuring the area of the resultant contact patch.¹ The weights listed are “as-tested” with the driver, instrumentation, and ½ tank of gasoline.

Table 1: Vehicle Parameter Data

Vehicle Data		
Make:	Ford	
Model:	Explorer	
Model Year:	2011	
Date of Manufacture:	5/11	
Mileage:	329	
Tire Manufacturer:	Hankook	
Tire Model:	Optimo H426	
Tire Size:	255/50R20	
Recommended Tire Pressure: (psi)	35	
Fr. Wheel Arc lock-to-lock: (deg.)	70	
Str. Wheel lock-to-lock: (turns)	2.8	
Steering Ratio: (:1)	15.75	
Avg. Front Tire Contact Area: (in ²)	34.0	
Turning Circle: (ft.)	38.9	
Vehicle Weight as tested: (lb)	LF	RF
	1385	1291
Total Front Weight (lb)	2676	
	LR	RR
	1054	1082
Total Rear Weight (lb)	2136	
Total Weight (lb)	4812	
Published Curb Weight: (lb)	4695	

Steering Force Determination

Instrumentation was installed that allowed the monitoring and recording of vehicle speed, hand wheel (steering wheel) force, hand wheel position, and lateral acceleration. Two series of tests were performed.

The first series consisted of sinusoidal steering inputs while driving at steady speeds between 5 mph and 40 mph in 5 mph increments. Hand wheel inputs were approximately 180 degrees left

¹ Front tire contact patches are provided in Appendix I.

and right or approximately 0.8G lateral acceleration, whichever limit was reached first. Testing was first performed with the EPS functional and then with the EPS disconnected. Table 2 lists the ranges of maximum measured hand wheel forces, with and without power steering assist, for the nine test conditions that were tested.

Table 2: Results of Sinusoidal Steering Tests

Test Description Nominal Speed (mph)	Measured Force Range Without Assist (lb)	Measured Force Range With Assist (lb)
Stationary (asphalt)	73-80	2.2 – 5.2
5 mph	24-26	3.5 – 3.7
10 mph	28-32	3.5 – 4.5
15 mph	35-38	3.7 – 5.5
20 mph	33-43	4.0 – 6.0
25 mph	35-49	4.5 – 6.5
30 mph	30-51	4.5 – 6.2
35 mph	42-53	4.8 – 6.5
40 mph	47-53	4.2 – 7.2

Figure 2 shows the lateral acceleration vs. steering wheel force for all testing and highlights the difference in required force between assisted and non-assisted steering effort. The blue line represents average unassisted steering effort while the red line represents average assisted steering effort.

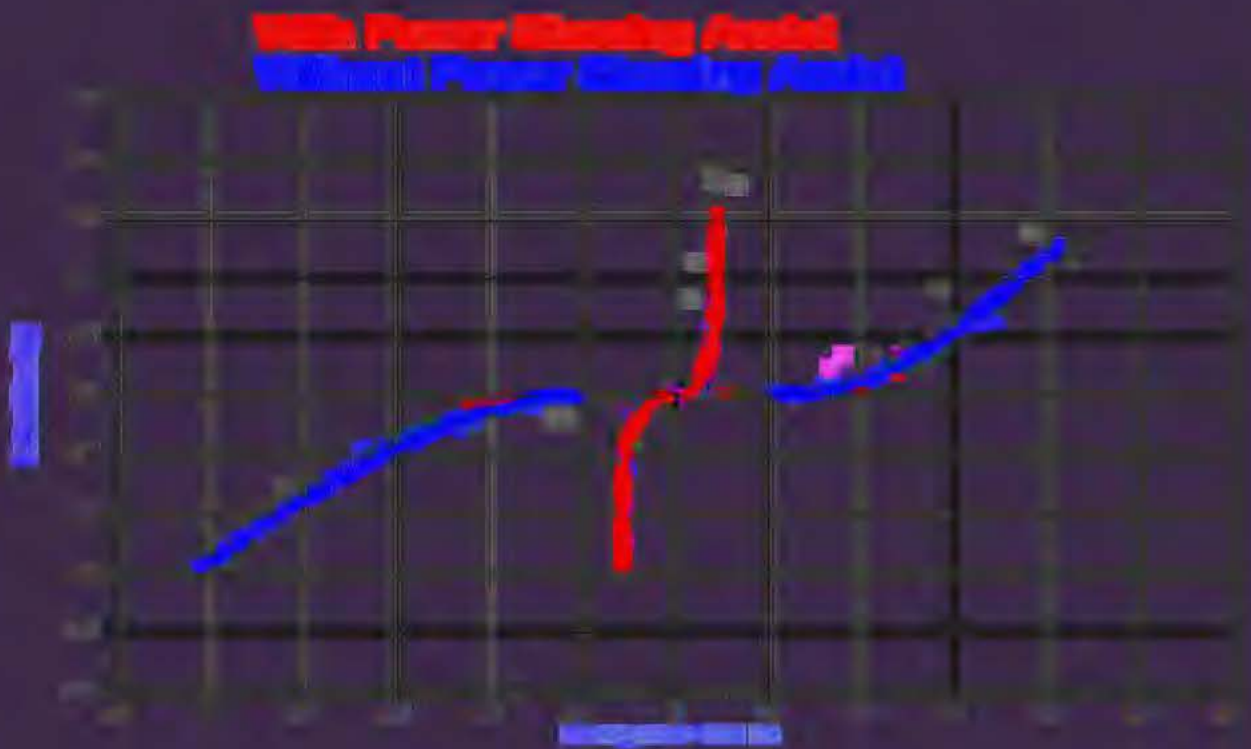


Figure 2: Lateral Acceleration vs. Steering Wheel Force - Assisted and Unassisted

The second series of force determination tests followed the ECE-79 test procedure.² This procedure involved entering a prescribed turn at a prescribed speed and measuring the force required to steer the vehicle. The speed and curve radii are different between assisted and non-assisted test conditions. Test parameters and results are shown in Table 3.

Table 3: ECE 79 Test Results

	Functional EPS	Non-functional EPS
Circle Radius (m/ft)	12/39.4	20/65.6
Entry Speed (kph/mpg)	10/6.2	10/6.2
Allowable Steering Force (daN/lb)	15/33.7	30/67.4
Measured Peak Steering Force (daN/lb)	1.6/3.5	8.9/20.1

² Detailed requirements of the ECE-79 test procedure are attached in Appendix II.

Heat Shield Testing

The engine is mounted transversely in the vehicle with one catalytic converter mounted vertically below each bank of cylinders. The EPS motor is part of the steering rack which is located at the rear of the engine compartment. As a result of this configuration, the rear catalytic converter is within approximately three inches of the EPS motor. Three heat shields are provided to protect the EPS motor from heat radiated by the catalytic converter. Figures 3 and 4 show the spatial relationship of the rear catalytic converter, the heat shields, and the EPS motor.

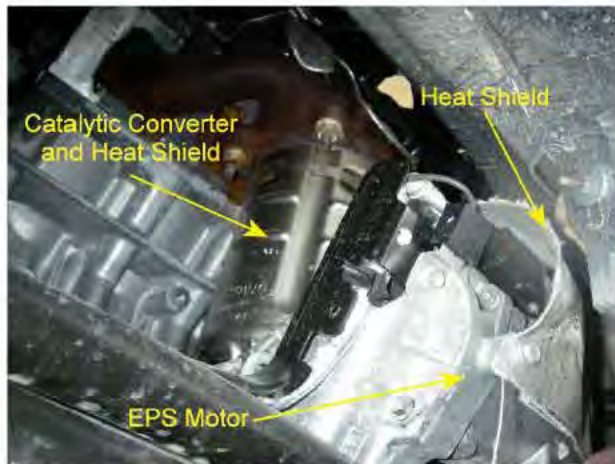


Figure 3: Catalytic and Heat Shields

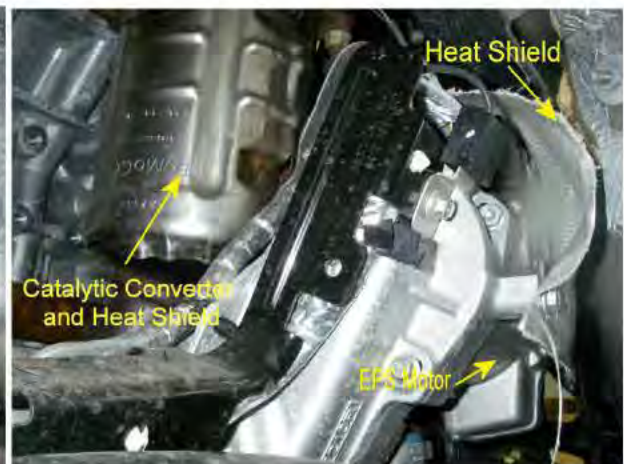


Figure 4: Catalytic and Heat Shields

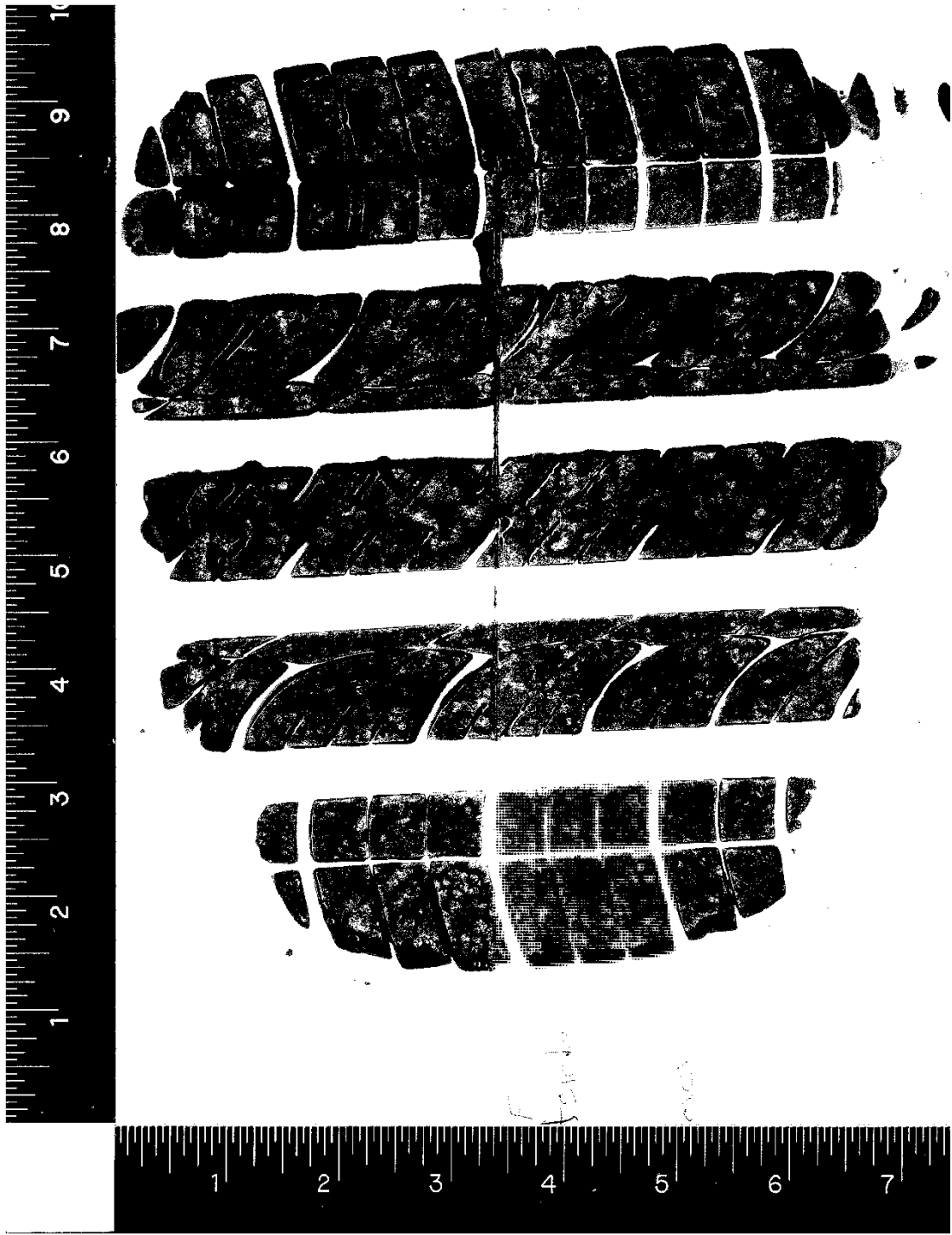
At the conclusion of the Force Determination Testing, testing was undertaken to determine the effectiveness of the heat shields that protect the EPS motor. Three thermocouples were installed on the vehicle. One was placed in front of the front bumper to determine ambient temperature; one was placed in the open area between the rear catalytic converter and the leading EPS heat shield; one was placed on the EPS motor, under the closest heat shield.

Four tests were performed at a nominal ambient temperature of 98 degrees F. The first test involved stop and go driving with steering inputs at speeds up to 35 mph. The second and third tests involved driving at mostly highway speeds with some slow speed maneuvers. The fourth test involved idling and very slow turning maneuvers at parking lot speeds with the air conditioner on. Table 4 lists a description of each test and the maximum recorded temperature for each location.

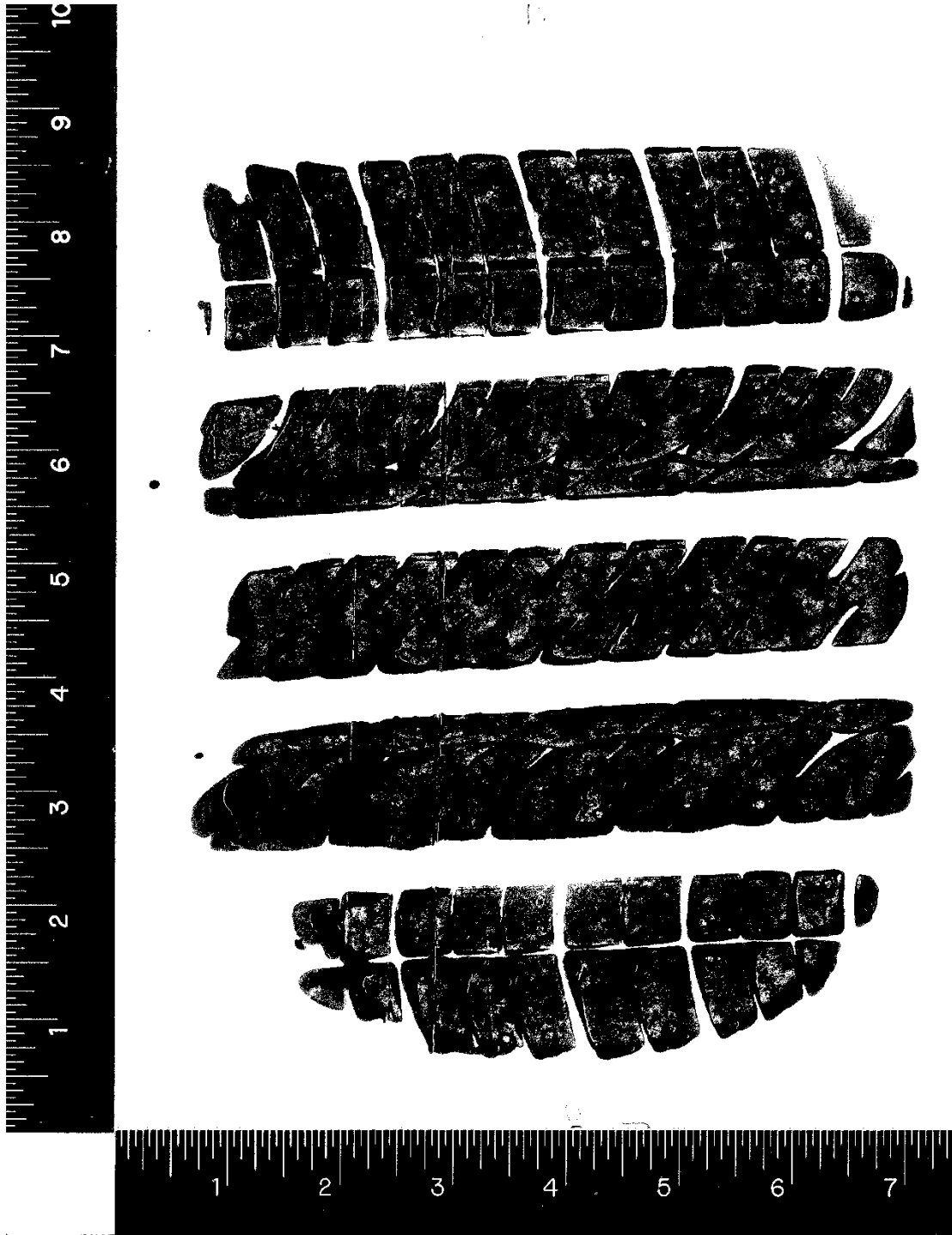
Table 4 – Results of Heat Shield Testing

Test No.	Description	Max Speed (mph)	Temp Range (deg F)		
			Ambient	Between Cat & EPS	At EPS
1	Slow stop & go	34	95-101	123-142	102-114
2	Highway and stop & go	63	95-99	151-162	115-118
3	Highway and stop & go	54	98-113	162-181	122-127
4	Idle and parking lot speed	7	104-109	183-194	132-138

Appendix I
Front Tire Contact Patches



Left Front Tire Contact Patch



Right Front Tire Contact Patch

Appendix II
ECE79 Test Protocol

Provisions for motor vehicles

6.2.1. It must be possible to leave a curve with a radius of 50 m at a tangent without unusual vibration in the steering equipment at the following speed:

Category M1 vehicles: 50 km/h

Category M2, M3, N1, N2 and N3 vehicles: 40 km/h or the maximum design speed if this is below the speeds given above.

6.2.2. When the vehicle is driven in a circle with its steered wheels at approximately half lock and a constant speed of at least 10 km/h, the turning circle must remain the same or become larger if the steering control is released.

6.2.3. During the measurement of control effort, forces with a duration of less than 0.2 seconds shall not be taken into account.

6.2.4. The measurement of steering efforts on motor vehicles with intact steering equipment.

6.2.4.1. The vehicle shall be driven from straight ahead into a spiral at a speed of 10 km/h. The steering wheel control effort shall be measured at the nominal radius of the steering control until the position of the steering control corresponds to turning radius given in the table below for the particular category of vehicle with intact steering. One steering movement shall be made to the right and one to the left.

6.2.4.2. The maximum permitted steering time and the maximum permitted steering control effort with intact steering equipment are given in the table below for each category of vehicle.

6.2.5. The measurement of steering efforts on motor vehicles with a failure in the steering equipment.

6.2.5.1. The test described in paragraph 6.2.4. shall be repeated with a failure in the steering equipment. The steering effort shall be measured until the position of the steering control corresponds to the turning radius given in the table below for the particular category of vehicle with a failure in the steering equipment.

6.2.5.2. The maximum permitted steering time and the maximum permitted steering control effort with a failure in the steering equipment are given in the table below for each category of vehicle.

STEERING CONTROL EFFORT REQUIREMENTS

Vehicle Category	INTACT			WITH A FAILURE		
	Maximum effort (daN)	Time(s)	Turning radius (m)	Maximum effort (daN)	Time(s)	Turning radius (m)
M1	15	4	12	30	4	20
M2	15	4	12	30	4	20
M3	20	4	12 **/	45*/	6	20
N1	20	4	12	30	4	20
N2	25	4	12	40	4	20
N3	20	4	12 **/	45*/	6	20