Technical Support Report for Regulatory Action

Prediction of

Vehicle Reference Frontal Area

by

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November 1977

NOTICE

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Abstract

Beginning with the 1979 model year, the dynamometer power absorption to simulate the vehicle road load during exhaust emission certification testing and fuel economy measurements will be predicted by the vehicle reference frontal area.

This report develops an equation to estimate the vehicle reference frontal area using the overall vehicle height and width. The reference area data and the overall height and width data used in this analysis were supplied by the vehicle manufacturers.

It is concluded that the product of the overall vehicle height, width and the coefficient, 0.80, yields a good approximation of the actual vehicle reference frontal area. Using this approximation, there is 80 percent confidence that the predicted value will be within $\pm$ 1.0 square feet of the actual reference frontal area. This is approximately 5 percent of the reference area of a typical vehicle.

This equation is recommended as a method for evaluation of submitted reference area data or for predicting vehicle reference frontal areas when empirical data are not available.

Purpose

This report proposes an equation to estimate the vehicle reference frontal area using the overall vehicle height and width as parameters. This equation may be useful for estimating vehicle reference areas when measured values are not available, or for preliminary evaluation of the accuracy of submitted reference area data. This report documents the data sources and methodology used in developing the proposed equation.

Introduction

In a previous technical support report, "Prediction of Dynamometer Power Absorption to Simulate Light-Duty Vehicle Road Load", (1)* it was concluded that the prediction model which utilizes the vehicle reference frontal area is the preferred approach. This method will be used to determine the dynamometer adjustment for exhaust emission certification and fuel economy tests beginning with the 1979 model year (2).

When this regulation was first proposed, General Motors commented that the vehicle reference frontal area could be adequately predicted by the product of the overall vehicle height and the vehicle width times 0.8. This report provides a thorough analysis and documentation of this method of predicting the vehicle reference frontal area.

Discussion

Beginning with the 1979 model year, the vehicle reference frontal area will be used to determine the dynamometer adjustment for EPA exhaust emission certification and fuel economy testing. For this purpose, the vehicle reference frontal area is defined as the area of the orthogonal projection of the vehicle onto a plane perpendicular to the longitudinal axis of the vehicle. This area is usually determined by analysis of engineering drawings, projection techniques from the actual vehicle, or planimeter measurements from photographs. Any of these methods are capable of yielding accurate results. However, unless a well automated system is used they can be time consuming. For example, the photographic approach requires the time delay of the development and printing of the photographic negative. Therefore, methods to predict the reference area from the overall vehicle height and width were considered desirable and worth investigating.

Reference area, overall height and overall width data were requested from the appropriate manufacturers for all vehicles used in the EPA road load project. The test fleet is described in Table 1 of the Appendix. These vehicles were selected to approximately represent the sales weighting of light-duty vehicles. The submitted reference area, height and width data are given in Table 2 of the Appendix.

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* Numbers in parentheses designate references at the end of the paper.

The model used to predict the vehicle reference area using the vehicle height and width was:

$$A = aHW \qquad (1)$$

where A = the vehicle reference area

H = the overall vehicle height

W = the overall vehicle width

a = a constant to be determined by the regression analysis

Equation 1 was chosen since the area should obviously be proportional to the product of the overall vehicle height and width. A constant term was not included in the model since any vehicle with vanishing height or width must have a zero reference area. Equation 1 was fitted to the reference area data and the vehicle height and width data by the least squares method. The results of this regression were:

Regression of Height Times Width
versus
Vehicle Reference Area

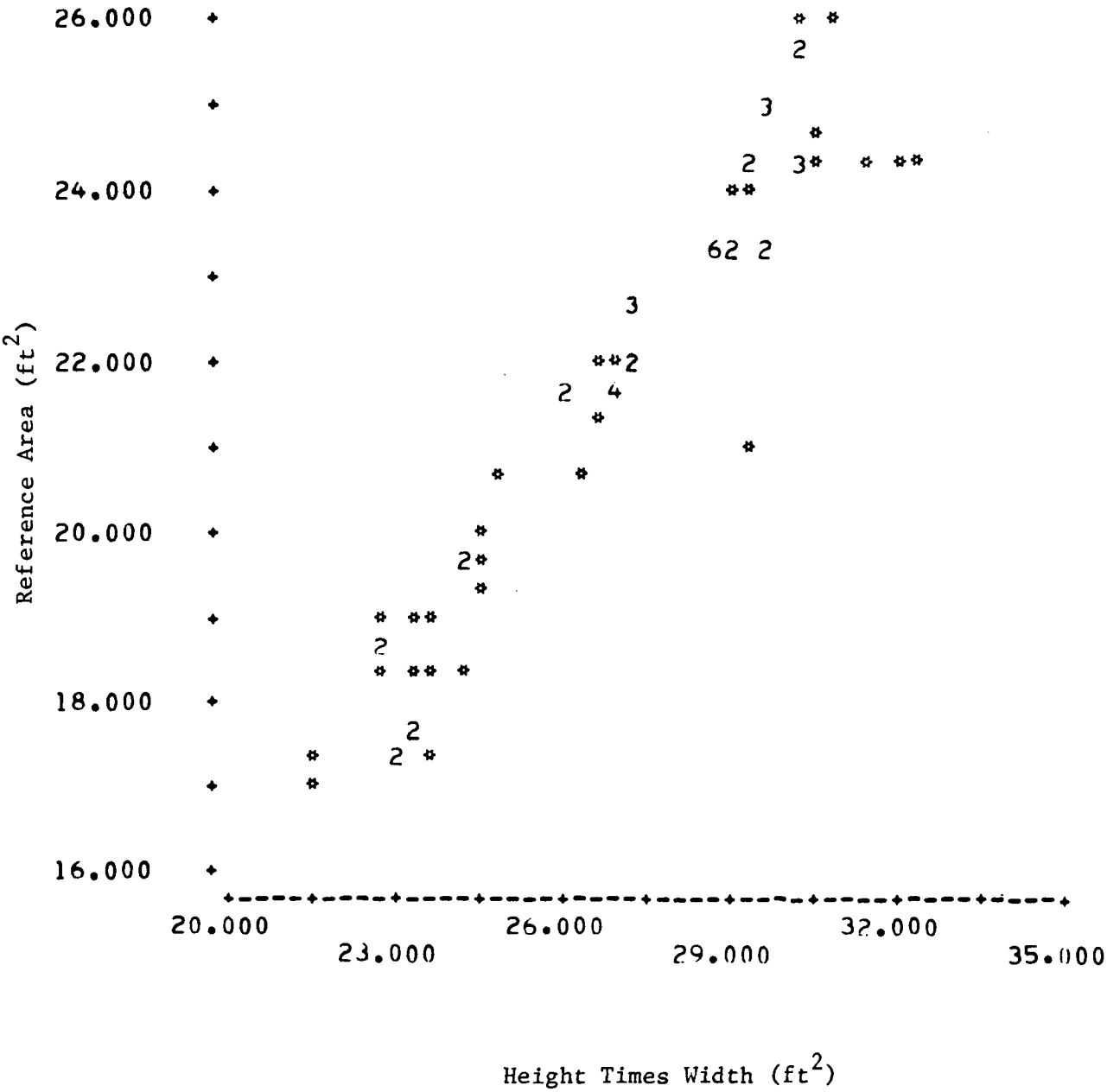
Regression Model: $A = aHW$

A = the vehicle reference area
H = the overall vehicle height
W = the overall vehicle width
a = 0.80
Sample Size = 67
Estimate of the Standard Error = 0.80 ft^2
Correlation Coefficient = 0.95

It should be noted that the regression coefficient is dimensionless. Therefore, the coefficient 0.80 is valid independent of the system of units. However, the system of units must be dimensionaly consistent. That is, the area must have the same units as the product of the height and width.

The data and the resulting regression line are plotted in Figure 1. The plot demonstrates the strong relationship between the reference area and the product of the vehicle height times width. The estimate of the standard error is approximately equivalent to one standard deviation of the residuals. Therefore, 68% of the data is expected to be within $\pm$ 0.80 square feet of the regression line. Figure 1 indicates there is only one datum which differs from the regression line by a much greater amount. The residuals of the measured values minus the predicted values of the regression were computed and are given in Table 3 of the Appendix. These residuals demonstrate that this atypical vehicle was an AMC Pacer. For this vehicle the predicted value was in error by 2.6 square feet or 12.1 percent.

Figure 1 - Scatter Plot of Reference Area Data
versus
Overall Vehicle Height Times Width



The general reference area shape of the Pacer is shown in Figure 2 along with the reference area shape of a more typical vehicle. Is is apparent from this figure that it is the wide "belt line" of the Pacer, together with the more rounded shape of the vehicle which causes the observed atypical results.

Conclusions

It is concluded that the Equation;

$$A = 0.80HW$$

is a good prediction of the actual vehicle reference area. There is approximately 80 percent confidence that the true vehicle reference area is within $\pm$ 1.0 square feet of the predicted value. There are, however, some atypical vehicles for which the prediction errors are much larger.

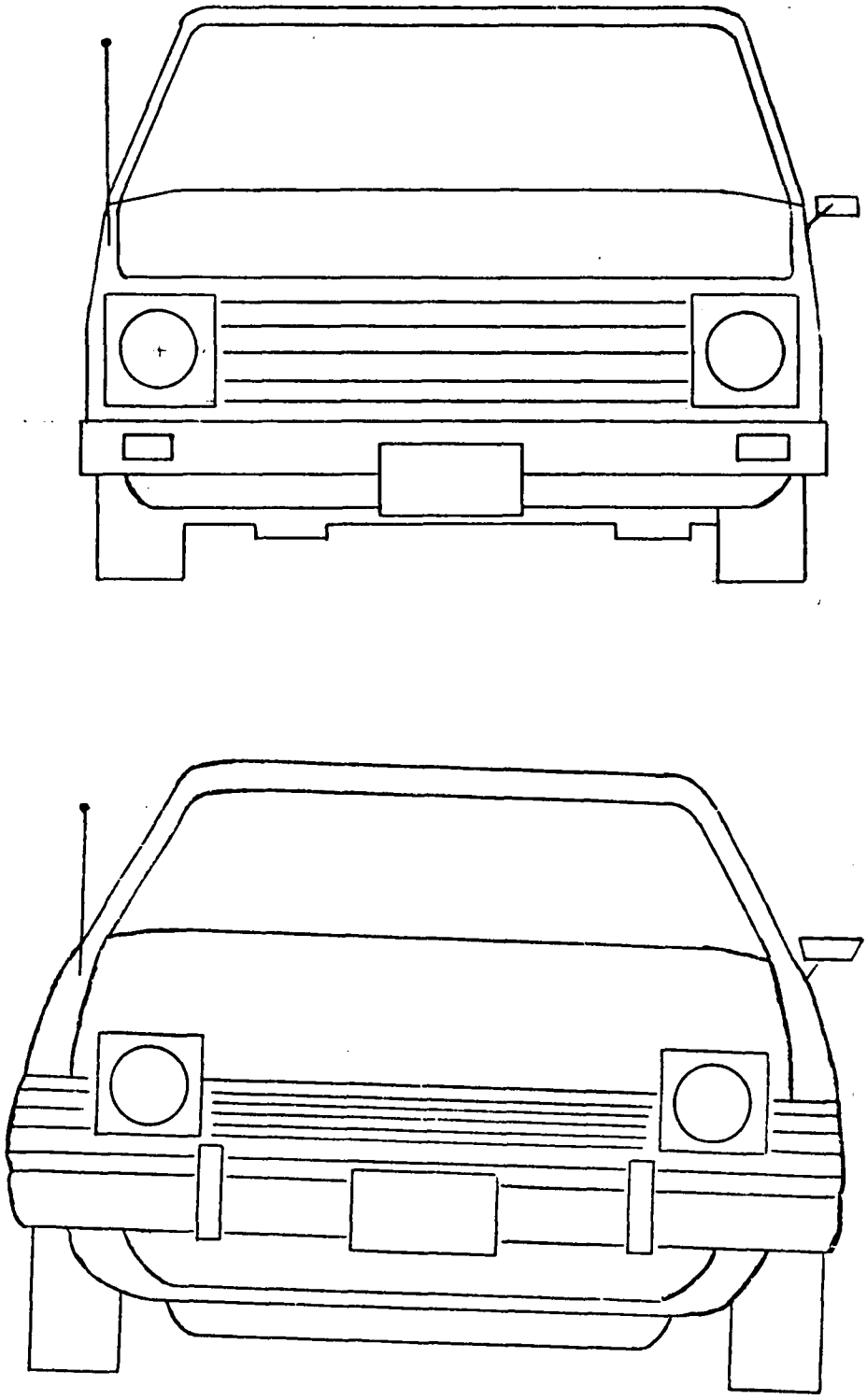
Recommendations

The equation can be useful in evaluating submitted reference area data. It may also be useful for predicting reference areas when empirical data are not available. It is recommended that the equation be used in this manner.

It is not recommended that the prediction equation be used in the regulatory process because of the inaccuracies in the case of atypical vehicles. If used in the regulatory process, the equation would penalize vehicles with the frontal surfaces similar to the AMC Pacer. However, there may be aerodynamic advantages of such rounded configurations.

In addition, if the product of the overall height and width were used in the regulatory process, manufacturers might tend to produce the largest reference area vehicles possible within a given height times width. It is considered inappropriate to impose this design oriented pressure when the vehicle reference area is considered the important parameter, not the vehicle height or width.

Figure 2 - Comparison of the Reference Area of a More Typical Vehicle to the Reference Area of the AMC Pacer



References

1. G.D. Thompson, EPA Technical Support Report for Regulatory Action, "Prediction of Dynamometer Power Absorption to Simulate Light-Duty Vehicle Road Load", April 1977.

2. "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines," Federal Register, Vol. 42, No. 176, September 12, 1977.

APPENDIX

TABLE 1
TEST FLEET

VEHICLE IDENTIFICATION NUMBER	MODEL YEAR	MANUFACTURER	MODEL NAME	BODY STYLE	TEST WEIGHT (LBS)
101	1974	Chevrolet	Impala	Sedan	4560
201	1975	Chevrolet	Chevelle	Sedan	4100
301	1975	Pontiac	Firebird	Sedan	3640
401	1975	Pontiac	Ventura	Sedan	3520
502	1975	Ford	Pinto	Sedan	2800
601	1975	Oldsmobile	Cutlass	Sedan	4250
804	1974	American Motors	Gremlin	Sedan	2970
901	1975	Chevrolet	Impala	Stationwagon	5250
1001	1975	Chevrolet	Vega	Sedan	2680
1102	1975	Ford	Granada	Sedan	3510
1201	1975	Buick	Century	Sedan	4140
1301	1975	Buick	Special	Sedan	4020
1401	1975	Buick	Skylark	Sedan	3720
1501	1975	Buick	Apollo	Sedan	3910
1601	1975	Chevrolet	Monza	Sedan	3490
1702	1975	Ford	Mustang Mach 1	Sedan	3000
1802	1975	Ford	Mustang	Sedan	3020
1901	1975	Buick	Skyhawk	Sedan	3200
2102	1975	Mercury	Capri II	Sedan	2570
2203	1975	Plymouth	Valiant	Sedan	3600
2301	1975	Buick	LeSabre	Sedan	4870
2401	1975	Buick	Estate	Stationwagon	5590
2502	1975	Lincoln	Continental	Sedan	5450
2602	1973	Mercury	Capri	Sedan	2350
2706	1975	Toyota	Corolla	Sedan	2470
2802	1975	Mercury	Comet	Sedan	3320
2906	1975	Toyota	Celica	Sedan	2760
3011	1975	Saab	99	Sedan	2710
3102	1975	Ford	Mustang Mach 1	Sedan	3320
3212	1975	Triumph	TR6	Convertible	2650
3304	1975	American Motors	Pacer	Sedan	3330
3402	1975	Ford	Maverick	Sedan	3320
3505	1975	Volkswagen	Rabbit	Sedan	2170
3613	1975	Honda	CVCC	Sedan	1900
3908	1975	Mazda	RX-3	Stationwagon	2680
4014	1975	Fiat	128	Sedan	2180
4102	1975	Mercury	Montego	Sedan	4560
4202	1975	Ford	Gran Torino	Sedan	4570
4402	1975	Ford	LTD	Sedan	4860
4507	1975	Datsun	280Z	Sedan	3110
4607	1975	Datsun	B210	Sedan	2310
4701	1975	Pontiac	Lemans	Sedan	4230
4801	1975	Oldsmobile	Cutlass Supreme	Sedan	4330
4903	1975	Dodge	Dart	Sedan	3610
5103	1975	Plymouth	Valient Custon	Sedan	4260
5203	1975	Plymouth	Gran Fury	Sedan	4840
5303	1975	Plymouth	Scamp	Sedan	3680
5403	1975	Plymouth	Valiant	Sedan	3620
5503	1975	Chrysler	New Yorker	Sedan	5120
5603	1975	Chrysler	Newport	Sedan	4840
5601	1975	Pontiac	Lemans	Sedan	4320
5701	1975	Oldsmobile	Delta 88	Sedan	4770
5802	1975	Ford	Granada	Sedan	3760
6002	1975	Mercury	Montego	Sedan	4500
6102	1975	Ford	LTD	Sedan	5020
6202	1975	Ford	Torino	Sedan	4420
6302	1975	Ford	Granada(1)	Sedan	3800
6402	1975	Ford	LTD	Sedan	5060
6502	1975	Ford	Torino	Stationwagon	5210
6702	1975	Ford	Gran Torino	Stationwagon	5000
6802	1975	Ford	Gran Torino	Sedan	4600
6909	1976	Volvo	264DL	Sedan	3290
8101	1975	Chevrolet	Corvette	Sedan	3850
8401	1975	Oldsmobile	Toronado	Sedan	5170
9101	1975	Chevrolet	Corvette(2)	Sedan	3820

(1) Same vehicle as 5802.
(2) Same vehicle as 8101, however head lamps up.

TABLE 2
REFERENCE AREA ESTIMATES

ID	HEIGHT (INCH)	WIDTH (INCH)	AREA* (FT)	AREA** (FT)
101	54.50	79.50	24.20	30.09
201	53.80	76.60	23.30	28.62
301	49.10	73.00	20.70	24.89
401	53.20	72.40	21.90	26.75
502	50.60	69.40	19.40	24.39
601	54.10	76.70	23.30	28.82
804	54.35	61.82	19.04	23.33
901	58.10	79.50	24.40	32.08
1001	50.00	65.40	18.40	22.71
1102	53.20	74.00	22.60	27.34
1201	54.10	79.00	23.30	29.68
1301	54.10	79.00	23.30	29.68
1401	54.20	72.40	21.90	27.25
1501	54.20	72.40	21.90	27.25
1601	49.80	65.40	18.70	22.62
1702	49.70	70.20	19.50	24.23
1802	50.00	70.20	19.50	24.37
1901	50.20	65.40	18.70	22.80
2102	51.00	66.90	18.90	23.69
2203	54.70	71.00	21.59	26.97
2301	54.60	79.90	24.20	30.30
2401	58.40	79.90	24.40	32.40
2502	55.30	80.25	25.90	30.82
2602	50.70	64.80	19.00	22.81
2706	53.54	64.96	18.40	24.15
2802	52.90	70.50	21.60	25.90
2906	52.86	63.78	17.70	23.41
3011	56.69	66.53	20.67	26.19
3102	49.70	70.20	19.50	24.23
3212	54.09	62.60	18.30	23.51
3304	55.06	76.60	21.05	29.29
3402	52.90	70.50	21.60	25.90
3505	55.50	63.40	20.00	24.44
3613	52.16	59.25	16.97	21.46
3908	55.12	60.80	18.19	23.27
4014	54.09	62.60	17.40	23.51
4102	52.60	79.30	23.40	28.97
4202	53.30	79.00	24.20	29.24
4302	54.70	79.60	26.00	30.24
4402	53.70	79.50	25.00	29.65
4507	51.38	64.96	17.64	23.18
4607	50.79	60.83	17.22	21.46
4701	53.40	77.40	23.30	28.70
4801	54.10	76.70	23.30	28.82
4903	53.80	71.80	21.50	26.83
5001	53.40	77.40	23.30	28.70
5103	54.70	71.00	21.59	26.97
5203	56.50	80.20	24.38	31.47
5303	53.50	71.80	21.37	26.68
5403	54.70	71.00	21.59	26.97
5503	54.40	80.40	24.30	30.37
5601	53.40	77.40	23.30	28.70
5603	54.80	80.40	24.52	30.60
5701	54.50	79.90	24.20	30.24
5802	53.20	74.00	22.60	27.34
6002	52.60	79.30	23.40	28.97
6102	53.70	79.50	25.00	29.65
6202	52.60	79.30	23.90	28.97
6302	53.20	74.00	22.60	27.34
6402	53.70	79.50	25.00	29.65
6502	54.90	79.00	25.60	30.12
6702	54.90	79.00	25.60	30.12
6802	53.30	79.00	24.20	29.24
6909	56.69	67.32	22.07	26.50
8101	48.10	69.00	17.20	23.05
8401	53.20	79.70	23.90	29.44
9101	48.10	69.00	17.20	23.05

** CALCULATED REFERENCE AREA USING HEIGHT TIMES WIDTH
* REFERENCE AREA SUPPLIED BY THE MANUFACTURER

TABLE 3
CALCULATED REFERENCE AREA

ID	AREA* (FT)	AREA+ (FT)	RESIDUAL (FT)	%DIFF
101	24.20	24.25	-0.045188	-0.187
201	23.30	23.06	0.239273	1.027
301	20.70	20.06	0.644741	3.115
401	21.90	21.55	0.346036	1.580
502	19.40	19.65	-0.252381	-1.301
601	23.30	23.22	0.078122	0.335
804	19.04	18.80	0.241720	1.270
901	24.40	25.85	-1.448642	-5.937
1001	18.40	18.30	0.101289	0.550
1102	22.60	22.03	0.570640	2.525
1201	23.30	23.91	-0.614828	-2.639
1301	23.30	23.91	-0.614828	-2.639
1401	21.90	21.96	-0.056842	-0.260
1501	21.90	21.96	-0.056842	-0.260
1601	18.70	18.23	0.473807	2.534
1702	19.50	19.52	-0.023460	-0.120
1802	19.50	19.64	-0.136266	-0.699
1901	18.70	18.37	0.328771	1.758
2102	18.90	19.09	-0.188352	-0.997
2203	21.59	21.73	-0.141230	-0.654
2301	24.20	24.41	-0.214397	-0.886
2401	24.40	26.11	-1.706484	-6.994
2502	25.90	24.83	1.066610	4.118
2602	19.00	18.38	0.620713	3.267
2706	18.40	19.46	-1.058999	-5.755
2802	21.60	20.87	0.730928	3.384
2906	17.70	18.66	-1.162740	-6.569
3011	20.67	21.10	-0.432741	-2.094
3102	19.50	19.52	-0.023460	-0.120
3212	18.30	18.94	-0.643316	-3.515
3304	21.05	23.60	-2.550583	-12.117
3402	21.60	20.87	0.730928	3.384
3505	20.00	19.69	0.307332	1.537
3613	16.97	17.29	-0.321517	-1.895
3908	18.19	18.75	-0.559934	-3.078
4014	17.40	18.94	-1.543316	-8.870
4102	23.40	23.34	0.057258	0.245
4202	24.20	23.56	0.639704	2.643
4302	26.00	24.37	1.633949	6.284
4402	25.00	23.89	1.109345	4.437
4507	17.64	18.68	-1.037416	-5.881
4607	17.22	17.29	-0.071517	-0.415
4701	23.30	23.13	0.174812	0.750
4801	23.30	23.22	0.078122	0.335
4903	21.50	21.62	-0.118425	-0.551
5001	23.30	23.13	0.174812	0.750
5103	21.59	21.73	-0.141230	-0.654
5203	24.38	25.36	-0.977131	-4.008
5303	21.37	21.50	-0.127561	-0.597
5403	21.59	21.73	-0.141230	-0.654
5503	24.30	24.47	-0.170800	-0.703
5601	23.30	23.13	0.174812	0.750
5603	24.52	24.66	-0.136123	-0.555
5701	24.20	24.37	-0.166051	-0.686
5802	22.60	22.03	0.570640	2.525
6002	23.40	23.34	0.057258	0.245
6102	25.00	23.89	1.109345	4.437
6202	23.90	23.34	0.557258	2.332
6302	22.60	22.03	0.570640	2.525
6402	25.00	23.89	1.109345	4.437
6502	25.60	24.27	1.330639	5.198
6702	25.60	24.27	1.330639	5.198
6802	24.20	23.56	0.639704	2.643
6909	22.07	21.35	0.717475	3.251
8101	17.20	18.57	-1.372668	-7.981
8401	23.90	23.72	0.178553	0.747
9101	17.20	18.57	-1.372668	-7.981

* REFERENCE AREA SUPPLIED BY THE MANUFACTURER
\+ CALCULATED REFERENCE AREA FROM THE REGRESSION