An Alternative Approach to "Measuring Horsepower and Torque Curves of a Car"

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The article in the September 2003 issue of *TPT* by John Ross Buschert of Goshen College entitled "Measuring Horsepower and Torque Curves of a Car" was excellent.[1] I attained similar results using existing automobile test data. Automobile performance tests done by magazines such as *Road & Track* are a treasure trove of good-quality physics data. Performance tests often contain all the data needed to replicate Professor Buschert's analysis of the power and torque output of automobile engines.

Buschert's students determined the power and torque of the engines of cars such as a 1986 Honda Accord LX and a 1997 Dodge Neon by conducting acceleration and coasting tests with the automobiles, by determining gear ratios experimentally, and by having the car weighed. This same information is provided in automobile performance tests. Older tests and tests from international car magazines tend to be the most thorough.

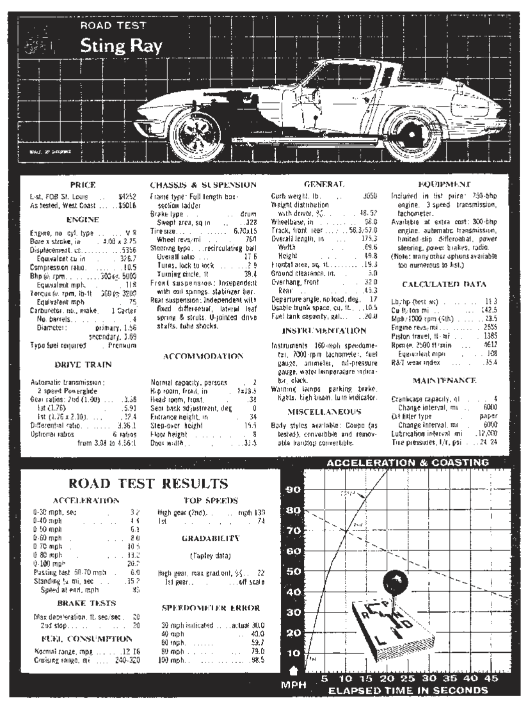
The Data

For example, in July 1964 *Road & Track* tested one of my favorite cars, a Chevrolet Corvette Sting Ray. *Road & Track* provided detailed graphs of speed versus time (Fig. 1) for acceleration and coasting, which can be mined for data similar to Buschert's (Fig. 2—converted to SI units; the car tested had a two-speed transmission). Also included in the *Road & Track* test were data on gear/speed ratios (1st gear: 74 mph/5000 RPM; 2nd gear: 23.5 mph/1000 RPM) and the weight (3050 lb) of the car.

Using this data and an analysis similar to Buschert's, I got power and torque curves for the Sting Ray's engine. The reader may find it interesting to compare the two methods of analysis.

The Analysis

I did not use Buschert's method of analysis exactly. However, I did use his overall approach of first determining frictional drag using coasting data and then determining power and torque from acceleration data.



ROAD TEST
Sting Ray

PRICE
Est, FOB St. Louis ... $4252
As tested, West Coast ... $5016

ENGINE
Engine, no. cyl. type ... V 8
Bore x stroke, in ... 4.00 x 3.25
Displacement, cc ... 5356
Equivalent cu in ... 326.7
Compression ratio ... 10.5
Bhp @ rpm ... 300 @ 5000
Equivalent mph ... 118
Torque @ rpm, lb-ft ... 300 @ 3200
Equivalent mph ... 75
Carburetor, no., make ... 1 Carter
No. barrels ... 4
Diameter: primary, 1.56; secondary, 1.69
Type fuel required ... Premium

DRIVE TRAIN
Automatic transmission: 2 speed Powerglide
Gear ratios: 2nd (1.00) ... 3.36
1st (1.76) ... 5.91
1st (1.76 x 2.10) ... 12.4
Differential ratio ... 3.36:1
Optional ratios ... 6 ratios from 3.08 to 4.56:1

CHASSIS & SUSPENSION
Frame type: Full length box-section ladder
Brake type ... drum
Swept area, sq in ... 328
Tire size ... 6.70x15
Wheel revs/mi ... 760
Steering type ... recirculating ball
Overall ratio ... 17.6
Turns, lock to lock ... 2.9
Turning circle, ft ... 39.4
Front suspension: Independent with coil springs, stabilizer bar.
Rear suspension: Independent with fixed differential, lateral leaf spring & struts, U-jointed drive shafts, tube shocks.

ACCOMMODATION
Normal capacity, persons ... 2
Hip room, front, in ... 2x13.5
Head room, front ... 38
Seat back adjustment, deg ... 0
Entrance height, in ... 34
Step-over height ... 15.5
Floor height ... 8
Door width ... 31.5

GENERAL
Curb weight, lb ... 3050
Weight distribution with driver, % ... 48/52
Wheelbase, in ... 98.0
Track, front/rear ... 56.3/57.0
Overall length, in ... 175.3
Width ... 69.6
Height ... 49.8
Frontal area, sq. ft ... 19.3
Ground clearance, in ... 5.0
Overhang, front ... 32.0
Rear ... 45.3
Departure angle, no load, deg ... 17
Usable trunk space, cu. ft ... 10.5
Fuel tank capacity, gal ... 20.0

INSTRUMENTATION
Instruments: 160-mph speedometer, 7000-rpm tachometer, fuel gauge, ammeter, oil-pressure gauge, water temperature indicator, clock.
Warning lamps: parking brake, lights, high beam, turn indicator.

MISCELLANEOUS
Body styles available: Coupe (as tested), convertible and removable hardtop convertible.

EQUIPMENT
Included in list price: 250-bhp engine, 3 speed transmission, tachometer.
Available at extra cost: 300-bhp engine, automatic transmission, limited-slip differential, power steering, power brakes, radio.
(Note: many other options available too numerous to list.)

CALCULATED DATA
Lb/hp (test wt) ... 11.3
Cu ft/ton mi ... 142.5
Mph/1000 rpm (4th) ... 23.5
Engine revs/mi ... 2555
Piston travel, ft/mi ... 1385
Rpm @ 2500 ft/min ... 4612
Equivalent mph ... 108
R&T wear index ... 35.4

MAINTENANCE
Crankcase capacity, qt ... 4
Change interval, mi ... 6000
Oil filter type ... paper
Change interval, mi ... 6000
Lubrication interval, mi ... 12,000
Tire pressures, f/r, psi ... 24/24

ROAD TEST RESULTS

ACCELERATION
0-30 mph, sec ... 3.2
0-40 mph ... 4.5
0-50 mph ... 6.3
0-60 mph ... 8.0
0-70 mph ... 10.5
0-80 mph ... 13.2
0-100 mph ... 20.2
Passing test, 50-70 mph ... 6.0
Standing ¼ mi, sec ... 15.2
Speed at end, mph ... 85

BRAKE TESTS
Max deceleration, ft/sec/sec ... 20
2nd stop ... 20

FUEL CONSUMPTION
Normal range, mpg ... 12-16
Cruising range, mi ... 240-320

TOP SPEEDS
High gear (2nd) ... mph 130
1st ... 74

GRADABILITY
(Tapley data)
High gear, max gradient, % ... 22
1st gear ... off scale

SPEEDOMETER ERROR
30 mph indicated ... actual 30.0
40 mph ... 40.0
60 mph ... 59.7
80 mph ... 79.0
100 mph ... 98.5

Fig. 1. Road test data sheet from July 1964 *Road & Track.* Note acceleration/coasting curves.

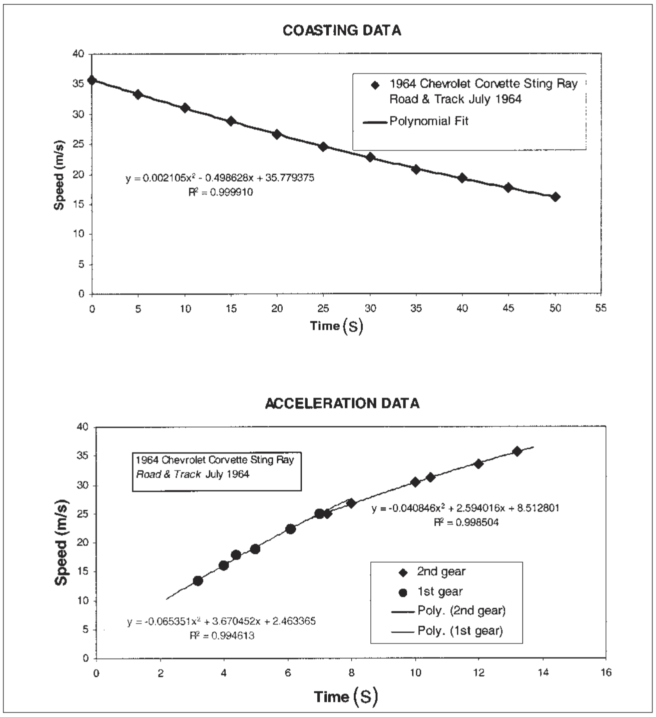


Fig. 2. Polynomials are fit to data read off the test data sheet acceleration/coasting curves.

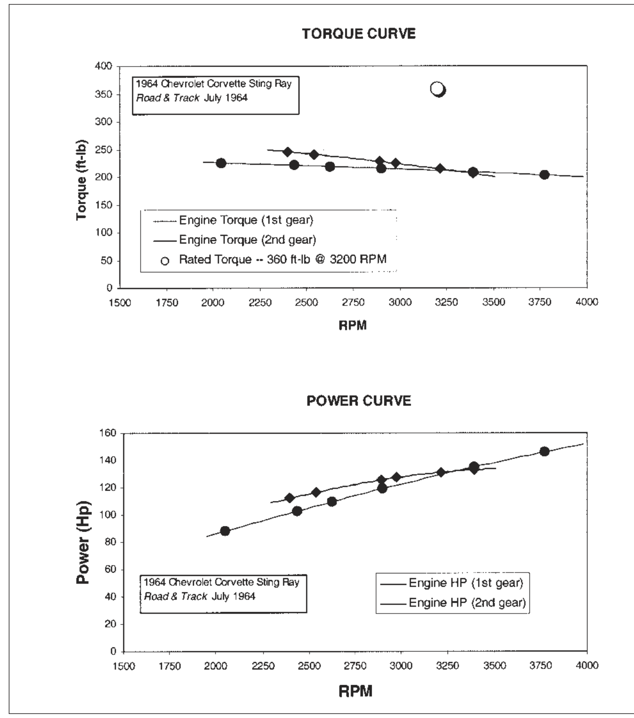


Fig. 3. The six marked points on each curve correspond to the six data points for each gear in the speed-vs-time plot for acceleration.

To both the coasting and acceleration data, I fit second order polynomials (Fig. 2). This provides a near-perfect fit to the coasting data. It provides a good fit to the acceleration data, too, and the shape of the second order polynomials is in general agreement with the shape of the original *Road & Track* acceleration graph.

The fit for the coasting data gives an equation for speed as a function of time for coasting (v_c):

$$v_c = p_c t^2 + q_c t + r_c \,. \tag{1}$$

(For the case of the Stingray, the coefficients are p_c = 0.002105, q_c = – 0.498628, and r_c = 35.779375.)

While coasting, the only forces acting on the car are drag forces. The total drag force (from all sources) on the car is then found by using Newton's second law of motion, recalling that acceleration is the first derivative of speed:

$$\Sigma F = m\,a$$

$$F_{drag} = m\, dv_c/dt = m\,(2\,p_c\,t + q_c). \tag{2}$$

m is the mass of the car, determined from the *Road & Track* test weight. I want drag as a function of speed, so I solve Eq. (1) for time using the quadratic formula and then plug that into Eq. (2). The result is

$$F_{drag} = m\,[q_c^{\,2} - 4p_c(r_c - v_c)]^{1/2} \,. \tag{3}$$

Now I turn to the data from the acceleration run. The fits in Fig. 2 give two equations for speed as a function of time for acceleration; one for acceleration in first gear, and one for acceleration in second gear (Fig. 2):

$$v_a = p_a t^2 + q_a t + r_a. \tag{4}$$

(For first gear, the coefficients are p_a = –0.065351, q_a = 3.670452, and r_a = 2.463365. For second gear, the coefficients are p_a = -0.040846, q_a = 2.594016, and r_a = 8.512801.)

The net force on the car is then equal to the vector sum of the forward force on the car due to the action of the engine acting through the wheels (F_{engine}) and the total drag force:

$$\Sigma F = m\,a$$

$$F_{\text{engine}} + F_{\text{drag}} = m\,dv_{\text{a}}/dt. \quad (5)$$

(The drag force will be negative.) The forward force, the power, and the torque produced by the engine are

$$F_{\text{engine}} = m\,dv_{\text{a}}/dt - F_{\text{drag}}, \quad (6)$$

$$P_{\text{engine}} = F_{\text{engine}}\,v_{\text{a}}, \text{ and} \quad (7)$$

$$\tau_{\text{engine}} = P_{\text{engine}}/\omega. \quad (8)$$

ω is the engine's rotational speed and can be determined from v_{a} using the *Road & Track* gear/speed ratios. F_{drag} is calculated from v_{a} using Eq. (3).

With these equations in hand, I can find v_{a} and dv_{a}/dt for any time t in the car's acceleration run. From these I can determine P_{engine}, τ_{engine}, and ω. A power curve for the engine is obtained by plotting P_{engine} versus ω; a torque curve is obtained by plotting τ_{engine} versus ω.

The Results

Figure 3 shows the power and torque curves that result from my analysis of the *Road & Track* performance test data (shown in English units as is customary for automobile data in the United States). The agreement between my results and the rated torque of the Sting Ray is not as good as in Buschert's examples, but that is not surprising because engine ratings in the early 1960s tended to be much more "optimistic" than they were in 1986 or 1997. Also, I did not compensate for the engine's moment of inertia as Buschert did—these effects were not as significant with the Sting Ray as they were in Buschert's test cars.

This approach to the problem has its advantages versus Buschert's approach. There's no need for equipment—professional car testers have already acquired the data. This means no cost. It also means no students pushing their cars to the limit in the name of their physics class. Here at Jefferson Community College, we have a very, shall we say, "enthusiastic and creative" breed of physics student. I once had to cancel a simple air-pressure potato gun project when students proceeded to get hundreds of dollars of material donated from the industries and shops at which they or their friends and family worked. They started to construct artillery capable of hurling large projectiles into the next county. I'd hate to think what sort of nitrous-fed monster would come rumbling up to the lab if I announced we would test actual cars.

This approach also has disadvantages compared with Buschert's approach. I cannot control the experiment, and the data is not optimized for this problem. This is most obvious in the acceleration data. The range of RPMs over which data is available is limited because the shift point in the test was done to maximize acceleration rather than to produce a nice batch of data for a physicist.

My hat is off to Buschert and his students for their most interesting experiment. They might be happy to know that speed shops charge a lot of money to hook a car up to a dynamometer and get the exact same information that the Goshen College physicists get in their physics lab.

Reference

1. J.R. Buschert,"Measuring horsepower and torque curves of a car," *Phys. Teach.* **41**, 355 (Sept. 2003).

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