

California State University, Fresno
Department of Mechanical Engineering

ME 159
Mechanical Engineering Design Laboratory

Factorial and Performance Testing of a Chevrolet 4.3 liter V-6 Engine

Equipment:

Chevrolet 4.3 liter V-6 engine, Dyno-mite dynamometer with computer data acquisition system

Objective:

Determine the fuel consumption of the Chevrolet 4.3 liter engine as a function of coolant temperature, load, and speed using the Latin Squares method. Also, predict the performance characteristics of a fictitious vehicle based upon engine performance data gathered.

Procedure:

Measure fuel consumption for prescribed torques (40, 80, 120, 160 ft-lbf), engine speeds (1800, 2400, 3000, 3600 rpm), and coolant temperatures (175, 185, 195, 205 °F) in accordance with factorial testing procedures. Measure fuel consumption rate for one extra point not in the Latin squares arrangement.

The sweep function allows the dyno operator to select a pre-programmed load to allow the engine to operate through the allowable engine speeds. The maximum safe speed allowed in this test is 4000 rpm. The student should set the lower limit of the engine speed to 1600 rpm and the upper limit to 4000 rpm. The rate of engine speed increase is 200 rpm/sec. After setting the lower rpm, increase the engine speed slowly to allow the dyno to load and maintain speed. Once the throttle setting is finalized, engage the sweep test. The data from previous experiments has resulted in the following relation for torque in foot-lbs and engine speed in rpm:

$$Torque = 3 \times 10^{-9} rpm^3 - 5 \times 10^{-5} rpm^2 + 0.22 rpm - 40.974$$

The data gathered will allow the student to construct the power and torque curves for the engine that will be used to predict the performance of the vehicle. Perform the testing at a coolant temperature of 205 F.

Report:

Show the Latin squares arrangement for fuel consumption. Calculate the K values for each combination and find the value for K_{ave} . Plot R_L versus load, R_S versus speed, and R_T versus temperature. Plot fuel consumption (lbm/hr), brake specific fuel consumption (lbm/hp hr), and brake thermal efficiency (%) versus power (hp) at maximum speed for both the maximum and minimum temperatures. Plot fuel consumption, brake specific fuel consumption, and brake thermal efficiency (%) versus speed for the maximum load and maximum temperature. Discuss how fuel consumption, brake thermal efficiency, and brake specific fuel consumption vary with load, speed, and coolant water temperature. Compare the actual fuel consumption rate for the extra point with the predicted fuel consumption rate.

HHV = 20,100 Btu/lbm for gasoline

Consider the following grid of variables:

	S ₁	S ₂	S ₃	S ₄
L ₁	T ₁	T ₂	T ₃	T ₄
L ₂	T ₄	T ₁	T ₂	T ₃
L ₃	T ₃	T ₄	T ₁	T ₂
L ₄	T ₂	T ₃	T ₄	T ₁

For a complete test, each of the sixteen grid points would be run at four temperatures. Here we run the test at only one temperature. Note that each row and each column in the grid has all four different temperatures appearing only once. This arrangement is not the only possible.

If we take the mass flow rate of fuel in the first row we have

$$\dot{m}_f = (L_1, S_1, T_1) = f_1(L_1) \times f_2(S_1) \times f_3(T_1)$$

$$\dot{m}_f = (L_1, S_2, T_2) = f_1(L_1) \times f_2(S_2) \times f_3(T_2)$$

$$\dot{m}_f = (L_1, S_3, T_3) = f_1(L_1) \times f_2(S_3) \times f_3(T_3)$$

$$\dot{m}_f = (L_1, S_4, T_4) = f_1(L_1) \times f_2(S_4) \times f_3(T_4)$$

If we multiply the four equations above, we obtain

$$\dot{m}_f(L_1, S_1, T_1) \times \dot{m}_f(L_1, S_2, T_2) \times \dot{m}_f(L_1, S_3, T_3) \times \dot{m}_f(L_1, S_4, T_4) = \\ f_1^4(L_1) \times \prod_{j=1}^4 f_2(S_j) \times \prod_{k=1}^4 f_3(T_k)$$

Let us define R_L as the product of the four mass flow rates at load L to the $1/4$ power (geometric mean). Thus

$$R_{L_1} = \left[\prod_{j=1}^4 f_2(S_j) \times \prod_{k=1}^4 f_3(T_k) \right]^{1/4} f_1(L_1)$$

We can do the same for L_2 , L_3 , and L_4 . Since the coefficients of $f_1(L_i)$ are the same in all cases, we can write

$$R_{L_i} = K' f_1(L_i)$$

Since we know R_L from experimental data, we know the function $f_1(L)$ except for the constant K'

$$f_1(L_i) = R_{L_i} / K'$$

Similarly

$$R_{S_j} = \left[\prod_{i=1}^4 f_1(L_i) \times \prod_{k=1}^4 f_3(T_k) \right]^{1/4} f_2(S_j) = K'' f_2(S_j) \\ f_2(S_j) = R_{S_j} / K''$$

and

$$R_{T_k} = \left[\prod_{i=1}^4 f_l(L_i) \times \prod_{j=1}^4 f_s(S_j) \right]^{1/4} \quad f_3(T_k) = K''' f_3(T_k)$$

$$f_3(T_k) = R_{T_k} / K'''$$

Combining the above equations gives

$$\dot{m}_f(L_i, S_j, T_k) = \frac{R_{L_i} R_{S_j} R_{T_k}}{K' K'' K'''} = K R_{L_i} R_{S_j} R_{T_k}$$

If L, S, and T are truly noninteracting variables, then K would be the same for all the tests in the Latin squares arrangement. Due to experimental error, the values of K will vary slightly. We can take the average value for K

$$K_{\text{avg}} = \frac{1}{16} \sum_{i=1}^{16} K_i$$

Thus

$$\dot{m}_f(L_i, S_j, T_k) = K_{\text{avg}} R_{L_i} R_{S_j} R_{T_k}$$

Values for each of the K's are determined from each grid point in the latin squares arrangement. The K value for the upper left hand corner is

$$K = \frac{\dot{m}_f(L_1, S_1, T_1)}{R_{L_1} R_{S_1} R_{T_1}}$$

We have now obtained the mass flow rate of fuel for any combination of the load, speed, and temperature. The variation of the K values gives some indication of the accuracy of the method. If the K values differ substantially from the average value, then the assumption of noninteraction is probably not true.

Equations for power, BSFC, and thermal efficiency

$$\dot{W}[hp] = \frac{F[lbf] L[ft] N[rpm] 2\pi[rad/rev]}{33,000 \left[\frac{ft-lbf}{min-hp} \right]}$$

$$BSFC[lbm/hr-hp] = \frac{\dot{m}[lbm/hr]}{\dot{W}[hp]}$$

$$n = \frac{\dot{W}[hp] 2245[Btu/hr-hp]}{\dot{m}[lbm/hr] HHV [Btu/lbm]}$$

Factorial Test of a Chevrolet 4.3 L Engine

L ↓	S→	1800 rpm	2400 rpm	3000 rpm	3600 rpm
160 ft-lbf		175 °F	185 °F	195 °F	205 °F
		lbm/hr	lbm/hr	lbm/hr	lbm/hr
120 ft-lbf		205 °F	175 °F	185 °F	195 °F
		lbm/hr	lbm/hr	lbm/hr	lbm/hr
80 ft-lbf		195 °F	205 °F	175 °F	185 °F
		lbm/hr	lbm/hr	lbm/hr	lbm/hr
40 ft-lbf		185 °F	195 °F	205 °F	175 °F
		lbm/hr	lbm/hr	lbm/hr	lbm/hr

$$\dot{m}(80\text{ ft} - \text{lbf}, 3000\text{rpm}, 195^\circ\text{F}) = \text{_____} \text{ lbm / hr}$$

Methodology for vehicle performance calculations:

Your assignment for the performance testing of the Chevrolet 4.3 liter V-6 engine is to predict the vehicle performance based upon the data collected from the engine and applying established engineering principles to determine the characteristics of a fictitious vehicle.

To predict the acceleration rates of the vehicle, the student must determine the force required to accelerate the vehicle based upon $F=ma$. At any given instant, the forces must be in equilibrium. Thus, if a vehicle is at cruise conditions, the force transmitted by the drive wheels to the roadway, should be equal to the drag force on the car exerted by the vehicle's motion through the air and the rolling resistance which is a function of tire construction, interaction with the road surface, and the weight of the vehicle. Under acceleration, the force available to accelerate the vehicle is the difference between the required force to maintain the vehicle at the present velocity and the force necessary to accelerate the vehicle, $F=ma$. The student will compute the available force to accelerate the vehicle and using the kinematic equations of motion, compute the velocity increase for each increment of time.

In this experiment, you will collect the performance data for full throttle operation. By utilizing the transmission and final gear ratios along with the rolling radius of the tires, you will be able to determine the propulsive force at any given instant. For purposes of this experiment assume that the parasitic power loss for the engine and drive train is given by the following expression:

$$Power_{parasitic} = 7.465e^{(0.021V)}$$

where: power is in horsepower and V is in mph

The rolling resistance power requirement is given by the expression:

$$Power_{rolling} = 0.0027(V^2) + 0.11(V)$$

where: power is in horsepower and V is in mph

The drag force of the vehicle can be calculated using the drag force equation from fluid mechanics and based upon the drag coefficient, C_d , projected frontal area of the vehicle, and the mass density of air at standard conditions. Please note that the power can then be calculated by multiplying the force by velocity. Please remember to check for unit consistency.

The student will need to write a program that calculates the force requirements of the vehicle at a given instant and velocity and compare to the propulsive force delivered to the wheels. When the propulsive force exceeds the forces acting opposite the vehicle's motion, the vehicle accelerates. The rate of acceleration is proportional to the magnitude of the force difference. The program should compute and compare the forces involved in small time intervals. For the purposes of this experiment, use a time delta of 0.05 seconds. Assume that when getting underway from a standing start, the time required for full engagement of the clutch is 0.50 seconds and when making a gear shift, that the dwell time is 0.30 seconds. When starting the vehicle from a standing start, assume the clutch is fully engaged at 2200 rpm. Assume that there is no wheel spin. Graph road speed and distance traveled as a function of time.

For fuel economy calculations at constant speed, determine the power requirements and compare with the fuel usage as determined by actual testing (factorial and performance). Note, that depending upon the transmission gear ratio selected, the fuel mileage will vary. For this experiment, calculate all possible modes of operation and then highlight the most fuel efficient mode.

Performance predictions of fictitious vehicle:

Let's consider a vehicle with the following characteristics:

Rear wheel drive

3000 pound weight class

3090 inertial weight class (1.03×3000)

$C_d = 0.32$

Projected frontal area (ft^2) = 24.2

5 speed manual transmission with the following gear ratios

1st 3.15

2nd 2.10

3rd 1.30

4th 1.00

5th 0.82

Rear end differential ratio: 3.55:1

Rolling radius of tires 14.6 inches

Assume for purposes of this simulation that each gearshift requires 0.30 seconds. Assume the initial start requires 0.50 seconds. Predict the following performance parameters:

1. 0-60 mph time in seconds, distance traveled.
2. ¼ mile ET and terminal speed
3. Maximum vehicle speed, in which gear is the maximum speed achieved?
4. For grading submit the program listing and results of the performance simulation.

Graph all simulated runs using Excel to show the speeds and distances as appropriate. Assume standard atmospheric conditions for the simulations.

The following graphs are required:

1. Vehicle velocity in each gear versus engine rpm
2. Drive wheel torque versus vehicle velocity
3. Vehicle velocity as a function of time
4. Drag force, parasitic loss force, and rolling resistance force versus vehicle velocity
5. Sum of all resistive forces and drive wheel force versus vehicle velocity