

Using Simulation Software for Design of Experiment Training

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Design of Experiments (DOE) is an intrinsically hands-on topic; teaching students to apply the techniques in a classroom setting can be difficult. Especially difficult are students with differing backgrounds, for example, adult students that work full time in various industries but come together in the classroom. Finding examples that everyone can relate to is nearly impossible. Fabricated data sets reveal solutions too easily. In-class simulations of paper airplanes, shooting rubber bands, and catapults are interesting yet lack the complexity typically encountered in industrial processes. Bringing a process into the classroom or visiting a local manufacturing firm agreeable to playing host for a few weeks are both difficult to arrange.

Simulation Software

An acceptable compromise uses simulation software to allow students to design the experiment and then run the various treatments to generate their own data. The student sees the experiment through from start to finish, including analyzing data that contains some noise and unexpected results. While there are several simulation packages that work wonderfully, there is one in particular that generates unusually good results.

Hot Rod Burnout – Championship Drag Racing® (Bethesda Softworks, www.Bethsoft.com) is a program with no aspirations for use in Designed Experiment training. It is a simulation program for people interested in building a drag racer, allowing selection from 20 unique cars and providing over 60 vehicle components to adjust. Engine size, horsepower/torque (there are more than ten items on the engine that can be changed to alter power curves), tire configuration, suspension values, transmission, and center of gravity only begin the list of possible factors that can be customized for each car. Include environmental factors (wind, humidity, barometer, etc.) and the carefully crafted physics of the program (try installing a 1,000 hp engine in a '32 Ford Roadster and you'll go careening down the track until you either hit a wall or roll the car) to make the perfect simulation program, grabbing the attention of any DOE student.



Students build a car to their experimental specifications and take it to a test dragstrip for time trials (or to race against the computer). Each trial takes from 30-40 seconds to complete making it easy to gather plenty of data in a short period of time. Because the students “drive” their car, and because the program has built in variations from the environment, there is enough noise in the data to require the use of statistical data analysis.

Let's Race

The following designed experiment example uses *Burnout – Championship Drag Racing* as the simulation software and *Design-Expert*® software (Stat-Ease, Inc., www.statease.com) to speed along the actual experiment design and analysis. A 1969 Pontiac GTO chassis with a 389 c.i.d. engine served for this experiment. The following main factors were identified:

Factor	Name	Type	Low Actual	High Actual
A	Tires	Categorical	Stock Street	Race Only
B	Wing	Categorical	Low Force	High Force
C	Transmission	Categorical	2 Spd Auto	4 Spd Auto
D	Engine	Categorical	402 hp	599 hp
E	Center of Gravity	Numeric	50.00	60.00

The tires, wing, and transmission were not modified further, even though there are several characteristics for each that can be altered in the program. The program furnishes a center of gravity of 53%, so levels were chosen to bracket that value. The engine, however, captures the student's attention more than any other characteristic. Rather than include individual engine components as experimental factors, two engines were built with about 200 h.p. difference between them. Since there are many ways to configure the engine to attain that difference, the students learned a lesson in negotiation and compromise.

The *Burnout* program gives a screenful of data at the end of each race. However, choosing a response variable is vital in a well run designed experiment, so it is worthwhile to discuss with students how to explore their options. In the *Burnout* software, choices include trap speed, 1/8 mile time, 1/8 mile speed, 0-60 mph time, and many others. "Trap speed" was chosen as the response variable for this experiment.

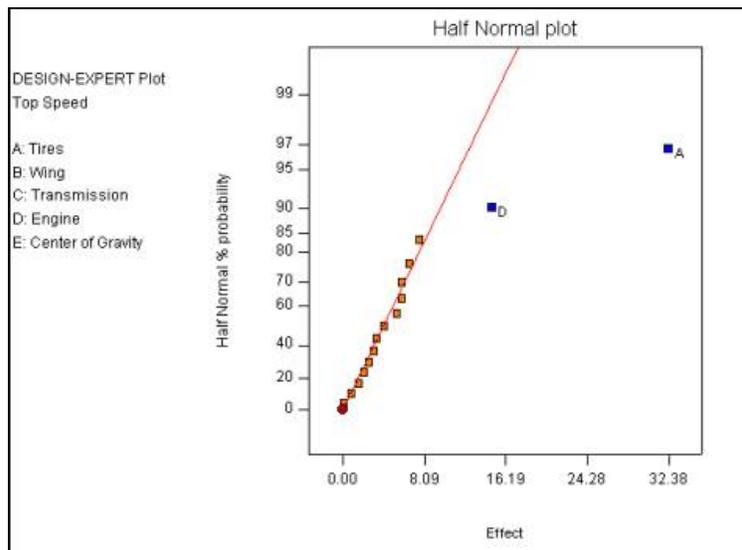
The experimental design as configured by the *Design-Expert* software, including the response variable results, can be seen below.

	Std	Run	Block	Factor A:Tires	Factor B:Wing	Factor C:Transmission	Factor D:Engine Hp	Factor E:Center of Gravity	Response Top Speed mph
	1	12	Block 1	Stock Street	Low Force	2 Spd Auto	402 hp	60.00	77
	2	9	Block 1	Race Only	Low Force	2 Spd Auto	402 hp	50.00	107
	3	11	Block 1	Stock Street	High Force	2 Spd Auto	402 hp	50.00	82
	4	13	Block 1	Race Only	High Force	2 Spd Auto	402 hp	60.00	107
	5	15	Block 1	Stock Street	Low Force	4 Spd Auto	402 hp	50.00	79
	6	3	Block 1	Race Only	Low Force	4 Spd Auto	402 hp	60.00	102
	7	7	Block 1	Stock Street	High Force	4 Spd Auto	402 hp	60.00	78
	8	6	Block 1	Race Only	High Force	4 Spd Auto	402 hp	50.00	103
	9	1	Block 1	Stock Street	Low Force	2 Spd Auto	599 hp	50.00	84
	10	8	Block 1	Race Only	Low Force	2 Spd Auto	599 hp	60.00	132
	11	14	Block 1	Stock Street	High Force	2 Spd Auto	599 hp	60.00	86
	12	10	Block 1	Race Only	High Force	2 Spd Auto	599 hp	50.00	143
	13	4	Block 1	Stock Street	Low Force	4 Spd Auto	599 hp	60.00	87
	14	16	Block 1	Race Only	Low Force	4 Spd Auto	599 hp	50.00	105
	15	2	Block 1	Stock Street	High Force	4 Spd Auto	599 hp	50.00	92
	16	5	Block 1	Race Only	High Force	4 Spd Auto	599 hp	60.00	125

It's a fractional factorial design that includes all five factors in only 16 runs. A check for aliasing (quite simple to do with the *Design-Expert* software) reveals the main effect factors confounded with 4-level interactions and the 2-level interactions confounded with 3-level interactions. This is a perfectly acceptable design given complete absence of prior knowledge regarding interaction affects in the software simulation. Since a couple of test runs on the *Burnout* software showed good race car repeatability, three runs were made for each treatment using the mean as the response.

What Makes Us Go Fast?

The *Design-Expert* software enables quick and easy data analysis. The figure below shows a half-normal plot of the responses, flagging factor A (tires) and factor D (engine) as significant factors. No other factors or interactions rose above the noise to be considered as effects.



The statistics provided by the *Stat-Ease* software clearly show ($p < 0.0001$) that the tires and engine have a major impact on the speed of the racecar, with tires being the most important. This result surprises many students. Most guess that engine size is the most important factor. However, these results are borne out by the comprehensive documentation included with *Burnout*, which states “Tires are the single most important element in drag racing.”

Now Everybody Race

One of the most gratifying aspects of training is when you can see the “light” click on when a student grasps a topic. Nothing seems to turn on more lights with students than hands on, interactive learning as provided by this simulation software. Will *Burnout-Championship Drag Racing* replace a comprehensive discussion of the fundamentals of designed experiments? Never. But anything that arouses student interest in a topic can be used as a learning tool. And anyway, when was the last time you had students ask to stay in training “just a little longer?”