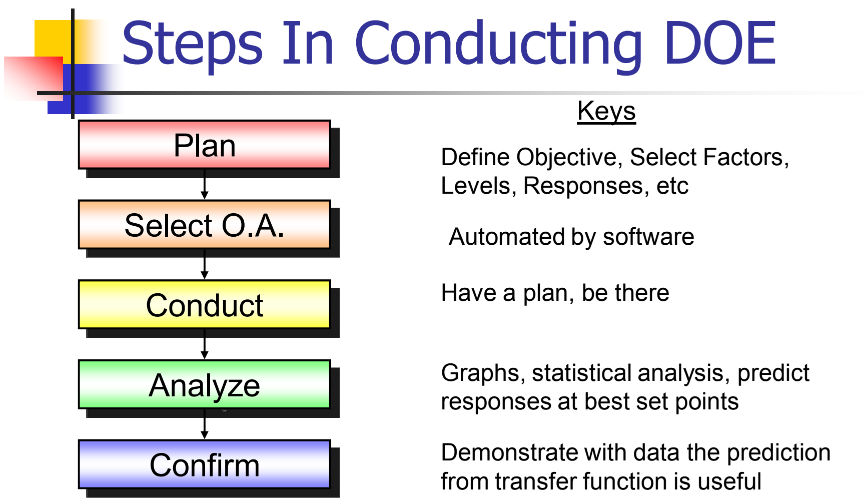
Example of Robustness Designed Experiment Using the Trebuchet

Over the last 20 years there has been much discussion regarding the concept of robust design. Even though there are numerous published case studies of specific applications many new to Designed Experiments are doubtful of the practicality of the approach to their technologies. One attempt we have made in teaching the concept of robustness is through the application of the technique to a trebuchet. Our strategy in the classroom has been to introduce students to a trebuchet simulation (Wintreb), conduct the experiment, then conduct confirmation experiments on the simulation. We also use an actual trebuchet we have built that tosses tennis balls.

We like to think about Design of Experiments as a five step process. The five steps are:



When conducting a Robustness DOE, we ask experimenters to divide their factors into two types. The two types are control factors and noise factors. They are both factors of interest because we know or suspect they have an impact on the responses of interest. Control factors are those we can change with the current design concept with little or no cost impact. Noise factors, on the other hand, are known to have an effect on the response but we either cannot or choose not to hold them at specific levels during the actual use or production of the product. Generally noise factors are of three types:

customer imposed usage conditions (usage temperature and humidity are almost always noise factors for product designers) supplier variation in components and subsystems or manufacturing variation

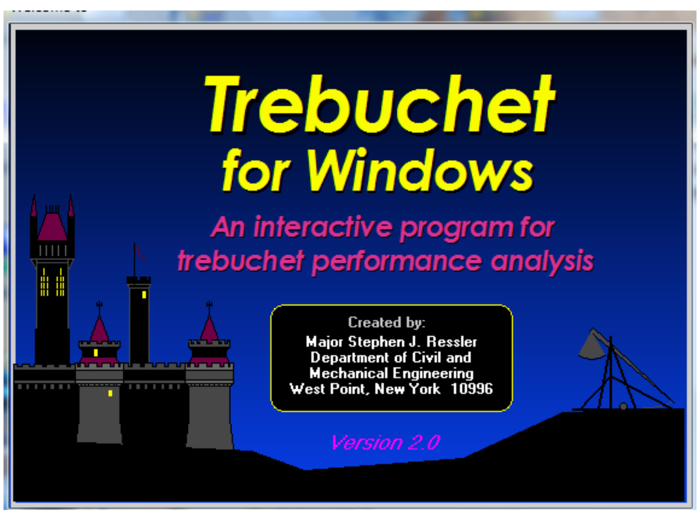
degradation over time being the third category of noise.

Fundamentally in a robust design we are attempting to find control factor settings such that we are sufficiently insensitive to the influence of noise factors.

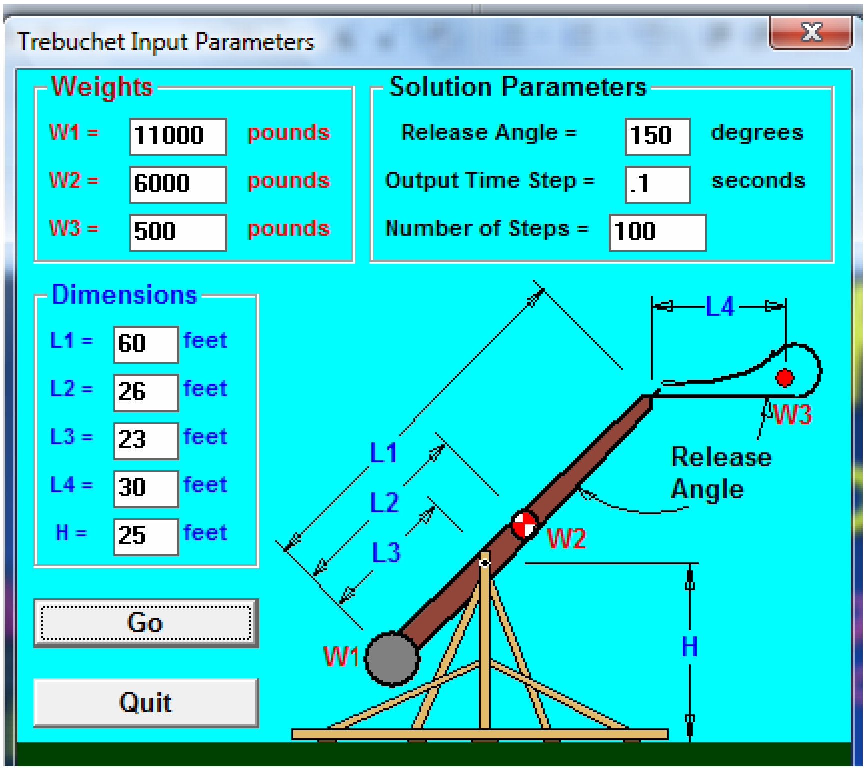
In the 21st century, the super weapons of choice are nuclear. In the 12th century, mechanical siege weapons were greatly feared. Complex mechanical firing mechanisms emerged in this time frame, and one of the most intriguing was the trebuchet (pronounced treh buh shay). In checking the internet, you will find an extensive list of sites for trebuchet hobbyists who are engaged in building various sizes of these devices (from small ones for tossing tennis balls to ones large enough to toss wrecked cars). Launsby Consulting uses a table top version that tosses tennis balls.

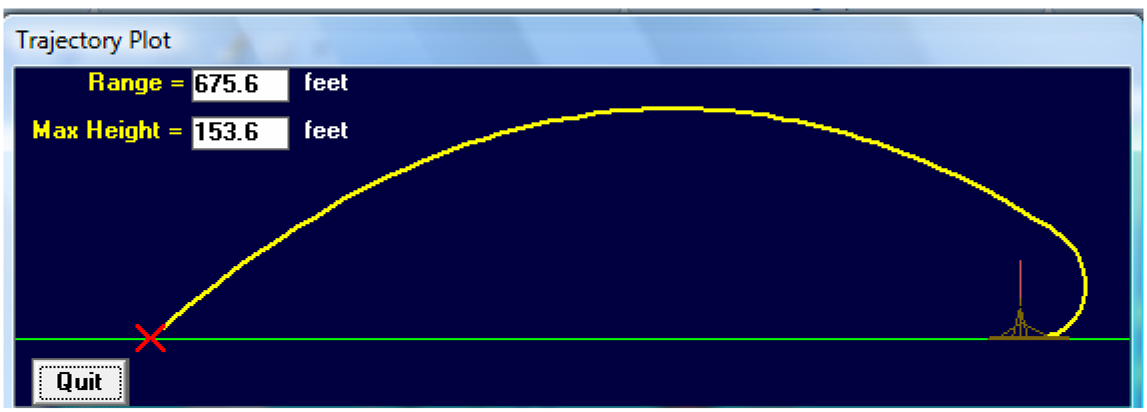
Unlike the catapult (a popular device used by many in Six Sigma training), the trebuchet is highly non-linear. Attempts to fit the device with a simple linear equation over a specific range of interest can provide very poor predictive ability (see for example the paper *Trebuchet Case Study,* at www.launsby.com under downloads/case studies).

In the robustness DOE we conducted, experimental data was obtained from WINTREB (a simulation written a number of years ago by Major Stephen Ressler. You can download WINTREB for our site.



This simulation allows you to study as many as nine factors. The following screen capture from WINTREB provides a cursory description of these variables. After initialization of the simulation, overall fight distance of the projectile as well as maximum height obtained during flight can be obtained.





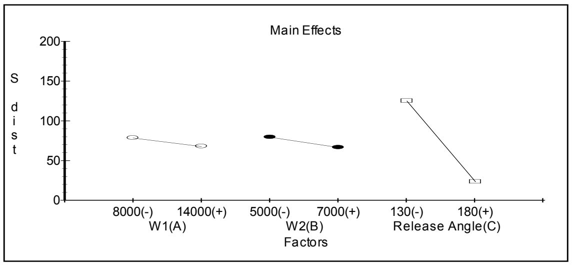
Many different types of designed experiments can be conducted using WINTREB (screening, modeling, etc.). We chose to select a scenario that would make the device amenable to a robustness DOE. In this scenario we decided to study W1, W2, and Release Angle as control factors (let's assume they can be readily adjusted by our army). The noise factor to be studied (only one in this case) is W3 (weight of the projectile being fired). In ancient time we could certainly make a case for there being variation in the weight of readily available boulders to toss with the device. Suppose the goal of the experiment is two-fold: 1. Determine if there are control factor settings that provide reduced variation in the face of our noise factor W3 (projectile weight). 2. Find the setting for the control factors that allow us to hit a target distance of 280 (while minimizing variation if possible).

In the following table we display the resultant data from our 3 factor Central Composite Inner array. The noise array is simple (one noise factor W3, at three levels…300, 500, and 700).

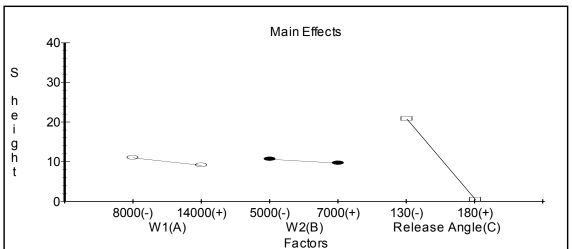
W1	W2	RelAngle	dist w/W3 at 300	dist w/W3 at 500	dist w/W3 at 700	height w/W3 at 300	height w/W3 at 500	height w/W3 at 700
14000	7000	180	263.2	297.9	323.7	66.5	66.9	66.8
8000	7000	180	262.4	279.6	278.3	66.7	67	67.5
8000	7000	130	479.8	338.7	232.3	222	198.6	176
8000	6000	155	608.9	520	424.8	113.3	120.8	121
14000	5000	180	277.7	317.6	346.8	66.5	66.9	66.8
11000	6000	155	712.4	646.1	567.4	116.6	126.9	131.6
11000	7000	155	674.2	614.2	542.1	111.1	120.8	125.5
8000	5000	180	288.8	313.9	314	66.9	67	68.9
11000	6000	180	275.7	314.1	327.9	66.7	66.8	67
14000	5000	130	753.5	630.2	511.9	299.4	282	265.1
11000	6000	130	646.9	517.4	394.3	267.8	247.5	226.6
8000	5000	130	552.7	383.8	250.6	247	220.1	195
11000	5000	155	741.3	673.4	590.8	118.4	130	135.3
14000	7000	130	699.8	589.7	495.5	281.6	264	247.2
14000	6000	155	764.6	723.7	664	113.6	126.5	134.8

Initial analysis was completed using DOE Wisdom software (visit www.Launsby.com/downloads for a free 15 day trial). Main effect plots of the standard deviation of the response are used to answer the first question --- does it appear we have a factor that provides for variance reduction?

Analysis Continued



Wow! Release angle at 180 provides reduced variation in the response (both distance and height)



Analysis of the above main effects plots suggests that release angle has a big impact on the standard deviation of the height and the standard deviation of the distance. Additionally, it appears a release angle of 180 is the best setting in order to reduce variation in either response.

The second question revolved around attempting to find other factors (W1 and W2) that allow us to hit a target distance of 280 (we will want to freeze release angle at 180 to take advantage of its ability to reduce variation regardless of the boulder weight). Making use of the desirability function built into DOE Wisdom software, we obtain the following solution:

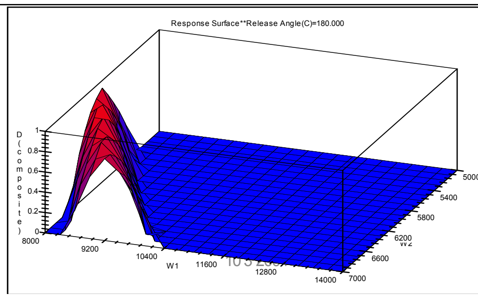
Analysis Continued

DOE Wisdom Prediction Equation

	dist	height	D(composite)	
	279.998	68.0978	0.994987	
95% CI:	± 183.221	± 31.0061	Not Available	
Constant	639.085	124.124	Not Available	
W1(A)	71.0400	13.2267	Not Available	8300.00
W2(B)	-19.1867	-4.90333	Not Available	6280.00
Release Angle(C)	-99.8500	-87.8333	Not Available	180.000
AC	-56.3667	-16.0083	Not Available	-0.900000
W1**2	-19.7286	-2.60952	Not Available	13430.0
Release Angle**2	-224.679	32.7905	Not Available	180.000

Predicted best setting to provide a mean distance of 280 and height of 68 regardless of the setting of noise factor, w3

Best settings are:
W1 =8300
W2=6280
Release angle =180



The DOE Wisdom Prediction Equation screen suggests that if W1 = 8300, W2 = 6280, and Release Angle is set at 180, we are predicted to achieve an average distance of 280 (regardless of the value for W3) with minimum variation. Verification trials at these control factor settings (with W3 set at 300, 500, 700) were run.

W1	**W2**	**Release angle**	**W3**	**Distance**	**Height**
8300	6280	180	300	270.1	66.8
8300	6280	180	500	297.6	67
8300	6280	180	700	297.1	67.8

These results were judged as being quite favorable.