

Name: _____

Lab 4

Date of lab: _____

Section number: M E 345. _____

Precalculations – Individual Portion

Experimental Design: Taguchi Design and RSM

Precalculations Score (for instructor or TA use only):	/ 20

1. **(10)** For the catapult used in this lab, construct a *full orthogonal Taguchi design array* (do not confuse with a *full factorial array*) that has 3 levels and 3 parameters (a , b , and c), with each level of each parameter tested 3 times. The parameters and levels are defined in the introduction to this lab. *Note: All parameters use levels 1, 2, and 3*, so use 1, 2, and 3 as the level numbers. Construct your array on the left side of the space below.

Full orthogonal array, 3 levels, 3 parameters 3 times

Fractional array, 3 levels, 3 parameters 2 times

2. **(8)** Similarly, construct a *shorter* fractional Taguchi design array that still has 3 levels and 3 parameters, but each level of each parameter is tested only 2 rather than 3 times. Construct your array on the right side of the space above.
3. **(2)** On your shorter design array above, indicate (by highlighting, circling, or some other mark) which runs required for the short array are different (extra) compared to the full orthogonal array.
4. Duplicate (or make a copy of) both of your above design arrays. You will hand in the originals to the TA, but you need to keep the copies or duplicates in order to proceed with the lab experiment.

Cover Page for

Lab 4

Lab Report – Group Portion

Experimental Design: Taguchi Design and RSM

Name 1: _____ Section M E 345. _____

Name 2: _____ Section M E 345. _____

Name 3: _____ Section M E 345. _____

[Name 4: _____ Section M E 345. _____]

Date when the lab was performed: _____

Group Lab Report Score (For instructor or TA use only):

Lab experiment and results, plots, tables, etc.	/ 50
Discussion	/ 30
TOTAL	/ 80

Lab Participation Grade and Deductions – The instructor or TA reserves the right to deduct points for any of the following, either for all group members or for individual students:

- Arriving late to lab or leaving before your lab group is finished.
- Not participating in the work of your lab group (freeloading).
- Causing distractions, arguing, or not paying attention during lab.
- Not following the rules about formatting plots and tables.
- Grammatical errors in your lab report.
- Sloppy or illegible writing or plots (lack of neatness) in your lab report.
- Other (at the discretion of the instructor or TA).

Name	Reason for deduction	Points deducted	Total grade (out of 80)

Comments (for instructor or TA use only):

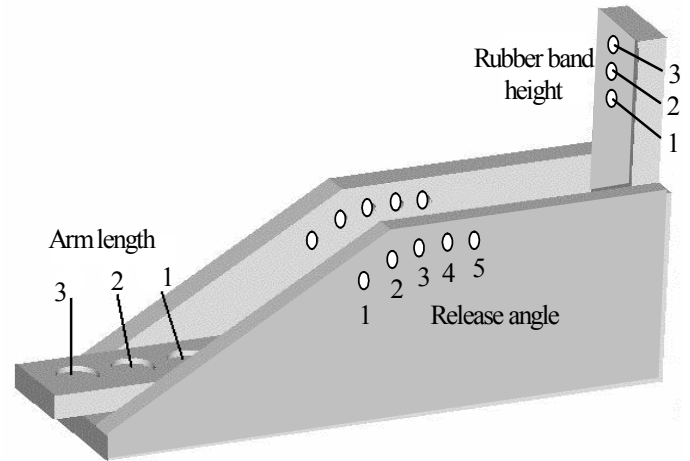
Experimental Design: Taguchi Design and RSM

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Latest revision: 26 September 2014

Introduction and Background (Note: To save paper, you do *not* need to print this section for your lab report.)

The *Taguchi experimental design technique* is discussed in detail in related learning modules. In short, it allows us to develop a *fractional factorial test matrix* in which P parameters are each tested at L levels, but with a significant reduction in the number of required experiments. This is accomplished by careful design of the test matrix, skipping some of the possible combinations of P and L , but in such a way that the effect of the skipped combinations is approximated by the process of *level averaging*.

In this lab, a simple catapult, constructed by Professor Timothy Simpson, is used to shoot ping pong balls. The goal is to shoot the balls as far as possible – to *maximize* the *response*, which is defined here as the distance the ping pong ball travels horizontally before it touches the ground. The catapult itself is a wooden device with several parameters that can be varied, as sketched to the right.



In this lab, three parameters are varied ($P = 3$), and each of the three parameters will be tested at three levels ($L = 3$). As discussed in the lecture, a full factorial analysis of this case would require $N = L^P = 3^3 = 27$ experimental runs. With the Taguchi method, we create a test matrix in which significantly *less* than 27 experimental runs are required, while still testing all three parameters, with each parameter still tested at three levels.

The three parameters to be tested, along with their levels, are listed below: [*The catapult is marked accordingly.*]

- **Parameter a: Rubber band height:** holes 1, 2, and 3 corresponding to levels 1, 2, and 3
- **Parameter b: Arm length:** cups 1, 2, and 3 corresponding to levels 1, 2, and 3
- **Parameter c: Release angle:** holes 1, 2, and 3 corresponding to levels 1, 2, and 3 [*Ignore holes 4 and 5.*]

Response Surface Methodology (RSM) is an alternate method to maximize (or minimize) a response. As discussed in related learning modules, RSM uses the *method of steepest ascent*. The procedure in brief:

- Start at some existing operating point.
- Take data around the operating point, varying *all* the independent parameters at the same time.
- Perform a regression analysis on coded variables to determine the direction of steepest ascent.
- March in the direction of steepest ascent until response y hits a peak value and then begins to drop. This is now a *new* operating point, hopefully with y much closer to its maximum value.
- Repeat as many times as necessary until the system operates as close as possible to optimum.

In this lab, a “virtual” experiment is used – you enter values of a , b , and c , and the website returns y . There is a (unknown) maximum value of y that you will attempt to find.

Objectives

1. Construct two Taguchi design arrays – a full orthogonal array and a shorter fractional design array.
2. Conduct experiments following the two experimental design arrays.
3. Analyze the results to predict which combination of parameters maximizes the response.
4. Design follow-up experiments to zero-in on the maximum response.
5. Use RSM to maximize response y of a virtual experiment with three input parameters a , b , and c .

Equipment

- wooden catapult with rubber band and ping pong ball [The rubber bands we use are called Advantage File Bands, #117B, 7 x 1/8 in., and are available at www.rubberband.com.]
- masking tape
- tape measure
- computer with Internet access (for virtual RSM experiment)

Procedure – Taguchi design arrays with the catapult

1. Compare your **full orthogonal design array** with those of your lab partners. Together, come up with a full orthogonal design array on which you all agree. Make sure your array has
 - 9 experimental runs
 - 3 levels for each parameter, with each level appearing *three times*
 - no unnecessary repeats of any parameter/level combination, as discussed in related learning modules
 Prepare an Excel spreadsheet of this design array so that you can enter experimental data.
2. Compare your **short design array** with those of your lab partners. Together, come up with a short design array on which you all agree. Make sure your array has
 - 6 experimental runs
 - 3 levels for each parameter, with each level appearing *two times*
 - no unnecessary repeats of any parameter/level combination, as discussed in related learning modules
 Prepare an Excel spreadsheet of this design array so that you can enter experimental data.
3. Have the TA check your **design arrays** to ensure they were generated properly.
4. Prepare the catapult for shooting by connecting the rubber band to the arm hook, running it through one of the holes on the vertical support, and then connecting it to one of the hooks on the vertical support.
5. Find a place on the lab floor or in the hall where you can safely shoot the ping pong balls. Practice shooting to establish a repeatable procedure for shooting and measuring the distance traveled by the ball.
6. Mark the launch location of the catapult with masking tape to ensure that the ping pong ball is always launched from the same location, and in the same direction. Masking tape may also be used to mark the horizontal distance the ball travels before hitting the ground. That distance should then be measured with the tape measure.
7. Conduct all necessary runs to complete *both* test matrices. *For best results, several shots should be measured for each row in the test matrix, in order to calculate an average distance for each run.* Use some engineering judgment here – if the distance is very repeatable with little scatter, take only a few measurements. But if the data have a lot of scatter, take *many* measurements in order to get a good average value.
8. When finished with the runs for *both* test matrices, return to the computer, but *do not remove your tape from the floor just yet – you may need to come back later for follow-up experiments, and use the same catapult.*
9. (8) Enter the experimental data into your spreadsheet, and calculate the **level averages** for each parameter and each level, as discussed in related learning modules. Do this for both test matrices (long and short).
10. (6) Generate three plots each for the two design arrays (full orthogonal *and* short, six plots in all):
 - level averages for parameter *a* versus levels of parameter *a*
 - level averages for parameter *b* versus levels of parameter *b*
 - level averages for parameter *c* versus levels of parameter *c*
11. (6) From your plots, determine the operating condition that is predicted to yield the **maximum response**.
 - *Predicted* maximum response for the **full orthogonal** design array:

Parameter *a*: Use level _____ .
 Parameter *b*: Use level _____ .
 Parameter *c*: Use level _____ .
 - *Predicted* maximum response for the **short** design array:

Parameter *a*: Use level _____ .
 Parameter *b*: Use level _____ .
 Parameter *c*: Use level _____ .
12. **Confirmation experiment(s)**: If either (or both) of these predicted operating conditions is *not* one of the tested operating conditions in one of your test matrices (in other words, it is a combination of parameters that you did *not* actually test), test it with the catapult to see if it indeed produces the maximum response.
13. (5) Print the sections of your spreadsheet that show your table of experimental results, the level averages, *and* the plots for both the full orthogonal and the short design arrays. Be sure to include any follow-up experiments in the table(s).

See attached Table(s) _____ and Figures _____ .
14. **Before you leave the lab, remove all the masking tape markings from the floor**, remove the tension from the rubber band, and return all equipment to the lab bench so that the equipment is ready for the next group.

Procedure – RSM with a virtual experiment

1. We use a *virtual* (fake) *experiment* for response $y = y(a, b, c)$. Instead of a physical experiment, you enter values of input parameters a , b , and c , and a spreadsheet calculates (“measures”) response y . Think of the spreadsheet as a “black box” that takes the place of an actual experiment. The spreadsheet is posted on the website.
2. **(1)** Starting at operating point: $a = 2.50$, $b = 50.0$, and $c = 0.250$, “measure” response y .

*Starting operating point:*Response $y =$ _____.

3. The bulk of this procedure should be done in Excel. *Note: For each run (some choice of a , b , and c), use the spreadsheet as a fake experiment to “measure” response y .* The useful ranges of input variables a , b , and c are, respectively, 0 to 5, 25 to 75, and 0 to 1 – *do not exceed these ranges, or the response may not be reliable.*
4. Choose a new sub-range of a , b , and c so that you can generate data *near* and *around* the operating point (to be used in the regression analysis). A good rule of thumb is to vary each parameter within $\pm 10\%$ of its useful range. [E.g., a is between 0 and 5, so consider varying a by $\approx \pm 0.50$ around the operating point.] With this in mind, vary all three parameters a , b , and c *at the same time*, and record response y for each case. A Taguchi design array is a very efficient way to vary the parameters, but it is not *necessary* to use a Taguchi array.
5. **(6)** Calculate coded variables for all three input parameters a , b , and c . In the spaces below, record the minimum and maximum value of each variable, along with those of its corresponding coded variable.

Equation for the coded variable: $x_1 = 2 \frac{(a - a_{\text{mid value}})}{a_{\text{range}}}$, with similar equations for the other two coded variables.

 $a_{\text{minimum}} =$ _____, $a_{\text{maximum}} =$ _____, $x_{1,\text{minimum}} =$ _____, $x_{1,\text{maximum}} =$ _____. $b_{\text{minimum}} =$ _____, $b_{\text{maximum}} =$ _____, $x_{2,\text{minimum}} =$ _____, $x_{2,\text{maximum}} =$ _____. $c_{\text{minimum}} =$ _____, $c_{\text{maximum}} =$ _____, $x_{3,\text{minimum}} =$ _____, $x_{3,\text{maximum}} =$ _____.

6. **(3)** Perform a regression analysis for y as a function of coded variables x_1 , x_2 , and x_3 . Calculate the direction of steepest ascent in coded variables, as discussed in class.

Direction of steepest ascent = (_____, _____, _____)

7. **(3)** Select appropriate increments for input parameters a , b , and c (you may round off for convenience as discussed in class and in the related learning modules).

 $\Delta a =$ _____. $\Delta b =$ _____. $\Delta c =$ _____.

8. **(3)** March in the direction of steepest ascent. If you did your algebra correctly, y should increase as you march, reach some maximum value, and then begin to decrease. Record the values of the input parameters and the corresponding maximum value of y at which you were able to maximize y with this marching scheme.

*New operating point:*Parameter $a =$ _____.Parameter $b =$ _____.Parameter $c =$ _____.Response $y =$ _____.

9. **(4)** Repeat the procedure as necessary to get closer to the optimum response.

*Near optimum operating point (as close you get):*Parameter $a =$ _____.Parameter $b =$ _____.Parameter $c =$ _____.Response $y =$ _____.

10. **(5)** Attach your spreadsheet showing the regression analysis and marching. Number the table and add a caption.

[A prize will be considered for the group that gets closest to the true optimum response.]

Discussion Questions

1. (5) Were you able to predict the correct conditions for maximum response using the *full orthogonal* Taguchi design array?
2. (5) Were you able to predict the correct conditions for maximum response using the *short* Taguchi design array?
3. (5) Did the full orthogonal array and the short array lead to the *same* prediction of maximum response? Discuss.
4. (5) Suggest some follow-up experiments that would be useful in further maximizing the response. What changes to the catapult (if any) would be required to conduct these follow-up experiments?
5. (5) Did the RSM technique march towards a better (larger) response, as claimed? Why or why not?
6. (5) The Taguchi method and RSM are similar in that both get you closer to the optimum response. Discuss the major differences between the two methods. Which one did you prefer, and why?