ASE 379L
Topic: Robust Design / Taguchi Method
HOMEWORK #5
Due: Feb 25, 2008
Please submit a hard copy.

Problem 1:
You are part of a team designing a spacecraft to perform a revolutionary science experiment at the Sun-Earth L_1 point (interior Libration point, R = 148,107,600 km). Initial analysis has indicated that the power system of choice is a solar array and battery combination. During the formulation phase, your team also decided that deployable, articulating solar panels are too complicated and entail too much risk. Therefore, the current baseline design utilizes body-mounted solar arrays.

Unfortunately, science requirements dictate that you must be capable of slewing the spacecraft bus up to 10 degrees off the nominal Sun-Earth line (see Figure 1 below). Because the baseline design calls for body-mounted solar arrays, this science-derived pointing requirement means that the solar panels will not always be perpendicular to the sun – causing a reduction in performance proportional to the cosine of the angle between the solar array normal vector and the vector to the Sun. Concern has been raised regarding the fluctuations that may occur in the power delivered from the solar array as the operating environment changes. As the systems engineer, one of your tasks is to look for a vehicle configuration that minimizes the fluctuations while simultaneously delivering the maximum amount of power possible. The configurations presently under consideration are shown in Figure 2. Despite their differences, note that each of the configurations have a trapezoidal cross-section. The cross-sectional geometry is as shown in Figure 3.

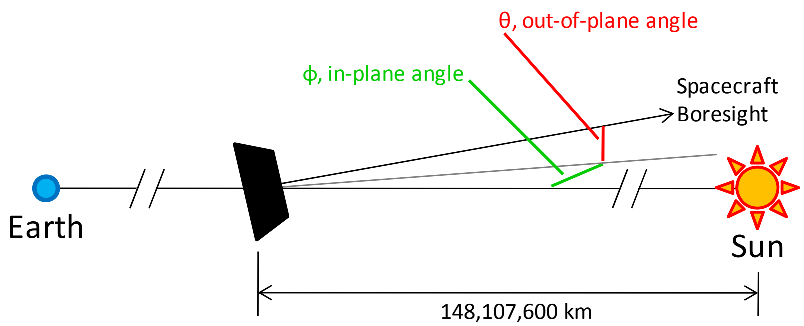


Figure 1. Overview of mission geometry.

Use the robust design techniques that we discussed in class (Taguchi Method) to determine the most robust vehicle configuration for *maximizing* power output. The power delivered by a solar array system may be approximated as:

$$P = \frac{S}{(1-\gamma)^{years}}\left(\frac{1\ AU}{R}\right)^2 A_n$$

where P is the delivered power (W), S is the specific power (W/m^2) of the solar array at 1 AU, γ is the solar array degradation/year, R is the distance from the Sun, and A_n is the surface area of the solar array adjusted for the Sun not being along the vehicle boresight. Also recall that 1 AU = 1.4959787e8 km. A_n for each of the configurations is given in Figure 2.

In your analysis, use an $L_9(3^4)$ array for the design parameters and an $L_4(2^3)$ array for the noise factors. These arrays are available in the "Introduction to Robust Design" lecture from Wednesday, February 13. The $L_9(3^4)$ array has four columns and you only need three for this problem – use the 1st, 2nd, and 4th columns (same as in the example I gave you in class). The variable ranges to be used in your analysis are as follows:

Variables			Variable Levels and Values		
			Low	Medium	High
Design Parameters	X_1	*a/b*	1	2	3
	X_2	β	20°	45°	70°
	X_3	body type	3D Trapezoid	Pyramid	Cone
Noise Factors	N_1	θ	0°	--	10°
	N_2	ϕ	0°	--	10°
	N_3	γ	0.025	--	0.035

Fix the surface area in all cases to 3 m^2 and use *a/b* and β in each instance to solve for *a* and *b*. The spacecraft will use triple-junction $GaInP_2/GaAs/Ge$ solar arrays with a specific power of S = 302 W/m^2 at a distance from the Sun of 1 AU. Science requirements dictate that the spacecraft must last 5 years.

3D Trapezoid

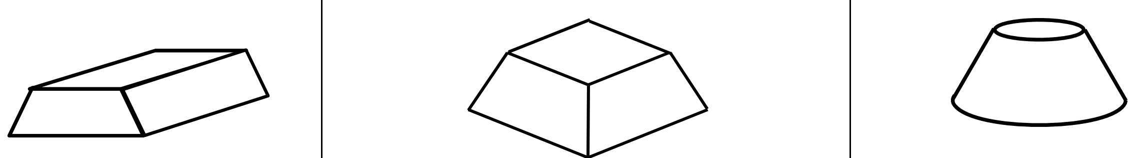
Historical Examples:
GRACE

Truncated Pyramid

Historical Examples:
Evil spaceships from *Stargate*

Truncated Cone (e.g. capsule)

Historical Examples:
Stardust



3D Trapezoid:

$$A_n = a^2\cos\theta\cos\phi + ab\cos(\pi/2-\beta-\theta)\cos\phi + ab\cos(\pi/2-\beta+\theta)\cos\phi$$

$$Surface\ Area = a^2 + 2ab$$

Truncated Pyramid:

$$A_n = a^2\cos\theta\cos\phi + (ab\cos\beta + b^2\sin\beta\cos\beta)\cos(\pi/2-\beta-\theta)\cos\phi + (ab\cos\beta + b^2\sin\beta\cos\beta)\cos(\pi/2-\beta+\theta)\cos\phi + (ab\cos\beta + b^2\sin\beta\cos\beta)\cos\theta\cos(\pi/2-\beta-\phi) + (ab\cos\beta + b^2\sin\beta\cos\beta)\cos\theta\cos(\pi/2-\beta+\phi)$$

$$Surface\ Area = a^2 + 4(ab\cos\beta + b^2\sin\beta\cos\beta)$$

Truncated Cone:

$$A_n = \pi\left(\frac{a}{2}\right)^2\cos\theta\cos\phi + \pi b(2a - b\sin\beta)\sin\beta\cos\theta\cos\phi$$

$$Surface\ Area = \pi\left(\frac{a}{2}\right)^2 + \pi b(2a - b\sin\beta)$$

Figure 2. Candidate spacecraft configurations and some useful properties.

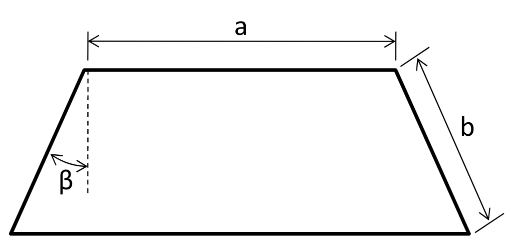


Figure 3. Spacecraft bus cross-section.

Please address the following questions:

a) Provide a 9x4 matrix with all 36 experiment results. Also show the 9x1 vector of average S/N.
b) Provide a single plot with the average S/N for each design parameter plotted against the level number.
c) Identify the most robust design parameter combination.
d) Provide a sketch (hand-drawn is OK) of the spacecraft bus cross-section for the design parameter combination you gave in part (c). In other words, redraw Figure 3 to scale and label the quantities a, b, and β.
e) Do the result identified in part (c) and (d) make sense? Provide a physical/geometrical explanation.
f) There are design considerations other than power that influence the choice of vehicle configuration. Give an example of another subsystem that may have a strong influence on vehicle configuration. Explain. What do you think the top three design parameters would be for this subsystem? What would be the quality characteristic (e.g. what are you trying to minimize/maximize/make robust)?
g) What do you think of the Taguchi Method? Do you find it to be a useful technique? Provide a brief, one-paragraph discussion.
h) Please provide a hard-copy of your code.

Some (hopefully) Useful Hints:

1) Start this assignment early!
2) I recommend solving this problem in MATLAB or a similar package. Excel will probably make this harder than it needs to be.
3) If you don't want to be creative with rearranging the surface area equations, consider using a root finding function like 'fzero' in MATLAB.
4) Note that my equations for A_n are in radians!
5) I have posted the results for three different test cases on Blackboard. Use these to make sure your model is working correctly. At the very least, make sure that the three appropriate entries in the 9x4 matrix in part (a) match the appropriate test case!

EXTRA CREDIT (10 points):

Traditionally, the Taguchi Method has been applied to engineering design efforts, as represented by the aerospace, auto, and computer industries. Research other applications (not related to engineering design) for the Taguchi Method. Sources may range from news articles to technical papers. Select an example application and discuss how Taguchi was used and the resulting impact to the product or process under consideration. (Write at least one page).