MASSACHUSETTS INSTITUTE OF TECHNOLOGY
16.888/ESD.77J MSDO

# 16.888/ESD.77J Multidisciplinary System Design Optimization (MSDO) Spring 2004

## Assignment 1

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| **Instructors:** | Prof. Olivier de Weck |
| | Prof. Karen Willcox |
| **Issued:** | Monday Feb. 9, 2004 |
| **Due:** | Monday Feb. 23, 2004 |

You are expected to solve **Part (a)** individually and **Part (b)** in your project team[1]. Each person must submit their own Part (a) but you may submit Part (b) as a group. Please indicate the name(s) of your teammate(s).

**Topics**: Multidisciplinary analysis, problem formulation, design of experiments

# Part (a)

## (a1) Motivation

Summarize in 5-10 sentences why you decided to take this class. What do you expect to learn? How does this knowledge fit in with your career or research plans?

## (a2) Chapter 1 – Principles of Optimal Design

After reading Chapter 1 of "Principles of Optimal Design" answer each of the following questions in 2-3 sentences and make a simple example to explain your answer:

(a2-1) In high-school you learned that the optimum of a function can be found by setting its first derivative to zero, i.e. searching for the condition $\partial f(x)/\partial x = 0$. Why is this not generally true in complex design problems? How can we modify a problem formulation to still search for places where the first derivative goes to zero? Make a simple example[2].

(a2-2) In traditional design optimization most design variables are continuous numbers, i.e. $x_i \in \mathbb{R}$. Can you give an example of a design problem where one or more design variables are not continuous? Explain in words and sketch.

(a2-3) What is your (crisp) definition of the concept of (engineering) "discipline"? Mention 2-3 different disciplines and explain how they differ.

[1] Teams of two are preferred, but teams of one or three are possible if coordinated upfront with the faculty.
[2] Hint: Section 1.4. *Topography of the Design Space*, might be particularly useful to answer this question.

(a2-4) Sketch and interpret the following function:

(a) $f(\mathbf{x}) = (x_2 - x_1)^4 + 8x_1x_2 - x_1 + x_2 + 3$
in the interval $-2 \le x_i \le 2$
(b) $f(\mathbf{x})$ same as above but add the constraint
$g(\mathbf{x}) = x_1^4 - 2x_2x_1^2 + x_2^2 + x_1^2 - 2x_1 \ge 0$

Where ($\mathbf{x}$*) is the minimum value of *f* with and without the constraint?

Note: This is the same problem as Problem 1.5 at the end of Chapter 1 (POD).

## (a3) Design of Experiments

1. Recall the airplane design experiment we did in Lecture 5. You can download the results from the MSDO 16.888 Server.
   a) Calculate the mean and variance for each experiment (9 experiments).
   b) Calculate the effect of each design variable setting (12 effects).
   c) What are the design variable settings of the predicted optimal airplane?
   d) What is the predicted range of the predicted optimal airplane? Do you expect this range to be physically realistic? Explain.
   e) Why might the predicted optimum airplane not be the true best design?
   f) If you consider both mean and variance results, does your ‘best’ airplane recommendation change? Explain how and why or why not.

# Part (b)

## (b1)

Pick a multidisciplinary system to analyze. You may choose a system aligned with your own research (preferred option) for which you have disciplinary models available, or you may choose one of the design problems

1. General aviation aircraft design
2. Space shuttle external fuel tank
3. Communications satellite constellation design
4. Supersonic jet design

For the multidisciplinary design problem that your team has chosen, write a short (~1 page) project proposal. You should address the following:

- Include a formal problem statement.
- Identify design variables, parameters, inequality constraints, equality constraints, bounds and objectives.
- What do you hope to achieve by the end of the semester?
- What is your current status and what do you see as potential difficulties?

Assemble all your design variables, parameters , constraints and objectives into a “master” table, showing, if applicable, in the columns the symbol, description, upper and lower bound, nominal initial value and unit of measurement.

**Note**: It is fine if this is a new problem and you are not yet sure what all relevant variables are, this problem will evolve over the course of the semester. A draft is perfectly acceptable at this point. However, you will need a simulation capability early in the semester (A2).

## (b2) Coupling and $N^2$ Diagram

For the problem that you have chosen identify the modules (see guidelines from Lecture 4), and identify the inputs and outputs for each module. For simplicity, limit the number of modules to below eight (8) at this point.

Place the modules on the main diagonal of an $N^2$-matrix, initially in a random order. Identify feedforward and feedback paths by using the identifiers for each variable from the “master” table you assembled in **(b1)**.

Rearrange the $N^2$-matrix to minimize the number of feedback loops.

## (b3) Block diagram

Sketch a block diagram that shows how the modules from **(b2)** work together and how you would wrap a trade space exploration tool or optimizer around your simulation model. You don't actually have to implement this (yet).