

Design of Experiments for Aerospace Products, Processes and Services

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ABSTRACT

If Design of Experiments (DOE) is so good why isn't it used more? Despite its power DOE has some demanding conditions. You don't have to be a statistician to conduct a successful DOE, however.

In Aerospace we are very often faced with the design, improvement or correction of a product, process or service. The most serious task is determination of the most relevant variables or factors that affect the final result or performance of the process or product in question. Once these factors have been established, we then need to determine an optimal combination of settings or levels for each factor. There is also the complicating possibility of interaction among the factors also. Design of Experiments (DOE) is an established statistical technique used on its own or in conjunction with a Six Sigma project to determine the strongest individual factors and if there is interaction among the factors. DOE is a powerful and pragmatic tool that can efficiently and effectively help us design a piece-part or whole system as well as manufacturing or transactional process or even a service offered as a product.

INTRODUCTION

In Aerospace we are very often faced with the design, improvement or correction of a product, process or service. The most serious task is determination of the most relevant variables or factors that affect the final result or performance of the thing in question. Once these factors have been established, we then need to determine an optimal combination of settings or levels for each factor. Design of Experiments (DOE) is an established statistical technique used on its own or in conjunction with a Six Sigma project to do these very things. DOE is a powerful and pragmatic tool that can efficiently and effectively help us design a piece part or

whole system as well as manufacturing or transactional process or even a service offered as a product.

The basics of DOE and 2^k experimental designs will be introduced. Application of DOE to piece-part and system design, manufacturing process optimization and services offered as products will be discussed. Typical examples of applications will be given. DOE application to the "chronic problem-process" and the new or novel process will be explored. DOE presents opportunities for joint collaboration between design and manufacturing functional areas. There are typical steps to plan and execute a DOE. DOE presents opportunities for joint collaboration between design and manufacturing functional areas before the design is finalized.

A full treatment of DOE can not be contained in a paper such as this. The intent of this paper to spark an interest in aerospace designers and manufacturing professionals to look further into this powerful tool. Text references are supplied at the end.

DOE BASICS

ORIGINS

When someone talks about the design of experiments they could simply be referring to deliberately designing a method to gather and analyze new data in an organized way. In this paper DOE will be referring to the method introduced by the noted statistician Ronald A. Fisher in his book *The Design of Experiments* in the 1930s. Fisher originally developed his method to optimize the production of agricultural crops. Some DOE terminology uses agricultural terms like "treatments" which we still use today.

In particular the method under discussion today will be the 2^k method. For instance a designed experiment with

k equal to three factors would be a 2^3 experiment. Each factor will be run at two levels, for instance a high and low. The two settings give us the 2 in a 2^k experiment. Since $2^3 = 2 \times 2 \times 2 = 8$, the entire experiment will be done in 8 runs.

Fisher might have been interested in high tomato yield for instance. If the factors of interest were soil acidity (no lime and lime added), irrigation (light irrigation and heavy irrigation) and fertilizer type application (Brand A and Brand B) this could be a classical 2^k method DOE with high tomato yield being the result of interest. In 8 patches of tomatoes with a pre-set combination of the three factors in each of the eight patches, the best and worst combination of acidity, irrigation and fertilizer could be determined. Moreover, if there were an interaction between acidity and fertilizer type, for instance, we could see that in the results.

That is great for tomatoes but you may be interested in shot peening spars to increase low cycle fatigue life. Shot peening is a special surface treatment where a surface is blasted with media such as cut wire shot in a special enclosure. The 2^k method still works. The result of interest is low cycle fatigue life. The factors of interest were chosen to be shot type (cut wire and ceramic beads), time (short time and long time), air pressure (high pressure setting and low pressure setting) and nozzle stand off distance (close and far settings). This will be a 2^4 experiment and can be done in 16 runs. From this experiment we can learn which of the four factors are the main factors and which main factors, if any have interaction with each other.

The really good news is that one does not have to be an expert in shot peening to conduct this DOE. The engineering or scientific explanation is not provided however from the results. But the important information of the “best combination of factors” has been identified.

If a second result of interest, say cost, was desired. The settings for the lowest cost could be determined from the same 16 runs. There is no guarantee that the setting of factors for best fatigue life and lowest cost will be the same. It is still a trade off decision but at least you will know the facts of the cost-fatigue life trade off.

So if this is so good, why don't we see more of this?

WHY DOE ISN'T USED MORE

DOE requires that all variables but the variables factors of interest be held constant. That is often difficult if not impossible to do perfectly. The fear of imperfection may keep people new to DOE from ever trying. To overcome this, remember that even the best experiments are not perfect. Eliminate or reduce as much stray variation as you can. Randomize any other variables that you cannot control. There are other techniques such as blocking that are available.

The idea is to understand the influential variables of your process. That does not mean one has to get it all right in the first experiment. DOE as well as most experimental techniques is iterative. We almost always learn something even from an imperfect experiment. By just conducting one experiment we learn enough to make the next experiment better and so on. If we never try, however, we will never solve anything. Better is better!

The power of the group should also be used in DOE also. The leader often feels that he or she must do most of the heavy lifting in an experiment design and execution. The value of a small group of subject matter experts (SMEs) to assist the leader is invaluable. These groups are often three to seven in size. The SMEs can greatly assist the leader overcome technical difficulties and details.

DOE relies on relatively simple mathematics to arrive at the conclusion of individual factor significance and factor interaction if any. The average output of all the high values of one variable and the average output of all the low values of the same variable constitute the basic math. When the two point are plotted on a graph and connected by a line we can infer how strong a factor that variable is. If the line is horizontal that variable is not a factor. The steeper the slope of the line the stronger the particular factor is.

Even so the use of a commercial statistical computer package such as Minitab® or Stat-Ease® is strongly suggested. Software tools such as these keep us from making arithmetic mistakes allowing the researchers to concentrate on the experimental design and data gathering. These software packages and others do the number crunching and produce superb tables, graphics and charts semi automatically. These powerful software tools can be run from a laptop computer and will help you build the design you need.

PART OR PRODUCT DESIGN

DOE can be used in the detail design of piece-parts or assemblies. For instance the desired output of interest might be compression strength of a piece-part. The factors for optimization might include cross section geometry, cladding, material type and end connector type. A DOE experiment could be devised to optimize the compression strength of this part. DOE is not meant to replace good design practice, finite element analysis and other techniques. What DOE can offer is a pragmatic and relatively quick assessment of design options. An interesting side note is that the designer need not know why the specific design works better to find out which design is better. Often, however, when a superior design is found through DOE, the subject matter experts (SMEs) have ready explanations for the reason behind the design success. These explanations may have been suspected before the DOE was done but there was no proof until after the DOE was done.