PROBABILISTIC METHODS TO DEFINE A DEVELOPMENT TEST CAMPAIGN IN THE ENGINEERING PROCESS

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1. THE DESIGN PROCESS: TWO FIGHTING APPROACHES

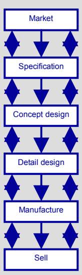
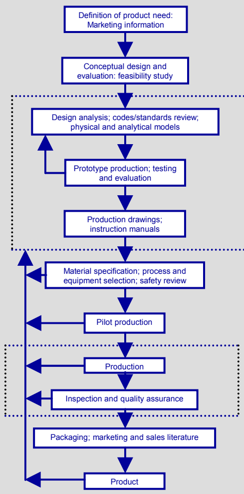


Figure 1-b: The Design Process; Concurrent Engineering

Nowadays, the design process is understood in two ways: the *Classical Approach* and the modern concept named *Concurrent Engineering*, both of them illustrated in figure 1 (figure 1-a & figure 1-b). Classical approach is more stepped than concurrent engineering yielding to a large time to market. In the opposite, concurrent engineering is more efficient, that is to say, it ensures short time to market, since it takes together all of the disciplines involved in the design process at the early stages of the product development. Also it is commonly mentioned that concurrent engineering provides better *Reliability* than the classical approach since it considers everything at the same time. The first question arisen is to assess whether such a statement is really true or not. There are many books appointing the healthiness of the concurrent engineering and showing success examples of this new approach. However, it should be also remembered that in December 1906 the famous British battleship Dreadnought (18000 tn.) was delivered to the Royal Navy, just 1 year and 1 day after the contract was signed (Figure 2). There are also others examples which tell us good about the no so modern practices. Everyone should think about their own professional experience and realize where is the key of the good design practice. Here is an answer: a good mapping process.

Figure 2:
HMS Dreadnought

Figure 1-a: The Design Process; Classical Approach



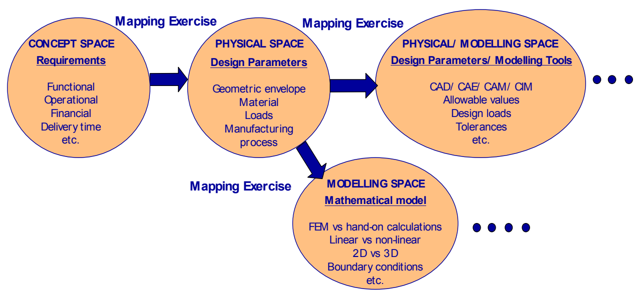
2. THE MAPPING PROCESS: THE UNCERTAINTY

From the definition of product needs, each step forward along the design process is performed through a mapping exercise (see figure 3). These mapping exercises allows to move from some type of conceptual requirements to something physical, around it we can think about and make decisions (i.e. freeze, modify, update, neglect, etc.). Without this mapping exercise it would not be possible to develop anything or almost anything. This mapping process, is basically the same in the two design flowchart depicted in figure 1. Also and strictly from a technical standpoint, it is basically the same now and 100 years ago. The better the mapping process is performed the better is the whole design process. Concurrent engineering has fault in many cases since too many opinions not necessary lead to a better understanding of the product, specially when much of this information is provided in a poor stage of maturity. Do not forget that concurrent engineering is commonly utilized as an excuse to make delivery times (and cost) shorter (and lower) than what is reasonable. The schedule is just a coloured bar in a spreadsheet but the average time needed to understand something is more or less the same, again, now and 100 years ago, even if you have all of the necessary information in front of you. Remember that neuronal connections in the human brain do not have any CAD/CAE or whatever tool to speed up their works.

Each time it is performed a mapping exercise a high degree of uncertainty could be involved and ….uncertainty. What is that? For engineering purposes it could be defined as the unpredictable and unexpected variation of any measurable entity (i.e. it belongs to reality). Even with a good understanding of the product there is always a technological limits which ensures that uncertainty is always present. It is very important to note that here *unpredictable, unexpected* and *measurable* have been joined together. This simple statement yields to some important conclusions as follows:

1.Since uncertainty is measurable, it is possible to include it in the design process in a rationale way.
2.Since uncertainty is unpredictable, how much accuracy could be expected from our designed product?
3.Since uncertainty is unexpected, it is not possible to avoid their effects.

Thus engineers has to perform calculations, validate their designs, and so on with these actual concept surrounding them. Unexpected could be tolerated but, definitively, unpredictable is an uncomfortable word for every mechanical engineer. However, since it is also measurable it is possible to obtain benefits from it. In this poster, it is utilized for identifying the main design variables and monitoring our effort when planning a test campaign. To do that it is necessary to add one term in our engineering dictionary (so important as Young Modulus): Multi-variant analysis



3. MULTI-VARIANT ANALYSIS USING MONTE CARLO SIMULATION

Multi-variant analysis refers to the simultaneously variation of a set of input variables (i.e. design variables) and the study of their effects on the behaviour of the system under observation. The nature of each design variable is complex and has important implications on the means utilized when performing multi-variant analysis. In fact, a proper modelling considers probabilistic distributions as the most suited means for modelling design variables. Thus design variables are considered as random variables and their effect on the system under study can only be assessed from a probabilistic standpoint. Monte Carlo simulation is a proper mean to simulate the random behaviour of a system. Monte Carlo is a very simple tool but good enough for engineering purposes. By using Monte Carlo in a FE model of the system (structure, coupon, etc), it is possible to identify the most important design variables and focus the study on those variables. Monte Carlo does not impose any additional constraint to the structure under study allowing variables to vary simultaneously. The statistical distribution provided by Monte Carlo could be not finest for some failure probability calculations but it is not the purposes of this presentation. Surface response methods based on DOE can also be utilized for modelling systems but only when there are no singularities within the region we are analysing. Figure 4 shows what multi-variant analysis focus on

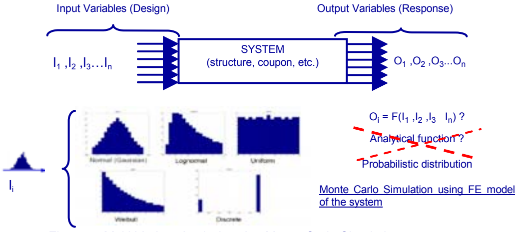
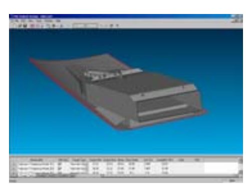


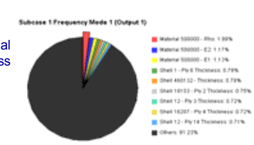
Figure 4: Multi-Variant Analysis using Monte Carlo Simulation

The whole behaviour of large structures is less dependent on the material properties. Thickness and other features also impact dramatically on them. Large structures do not take advantage of the extensive development campaigns.



Example of Large Structure (Inlet)

Results varying material properties and thickness



Results varying only material properties

4. APPLYING MONTE CARLO SIMULATION TO DEFINE A DEVELOPMENT TEST CAMPAIGN

In order to define a proper sample size in a development test campaign the following steps should be covered:

1) First check the behaviour of your FE model allowing the physical properties of your structure to vary in a typical range (say 7% from the nominal value for composites). Also It should be varied the geometrical features of the structure in such a percentage from the nominal values.

2) From step 1, it will be identified the most important design variables leading the behaviour of the structure. These design variables have to be linearly correlated with the requirements stated for the structure (allowable stress, max/minimum displacements, frequencies and whatever). Linear correlations have to be strong enough (higher than 0.7 is recommended). Non-linear correlation is beyond the scope of this poster.

3) Design variables with no strong correlation with requirements can be neglected. For these cases either a null effort or a minimum one (5 samples) can be allocated.

4) The requirements have to be sorted considering their relative importance. This fact allows to define some tolerance interval for some requirements whilst allows another become goals.

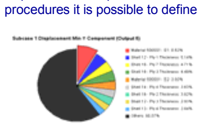
5) Assuming hard and soft requirements it is possible to provide the necessary intervals where properties can vary while fulfil the requirements.

6) Once it is know the range within the boundaries of the design variable can vary it is obtained the sample size to be allocated.

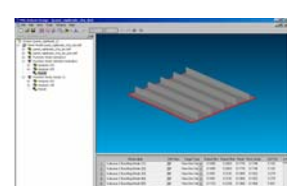
It is important to note that as a structure become larger, the behaviour depends more on the mean values of the physical properties than in the type of probability distribution and the variance from the mean values.

The following studies have been carried out using MSC/ROBUST DESIGN. It was performed 100 shoots.

The whole behaviour of small (or simples) structures can be efficiently monitored using multi-variant analysis. From requirements it is possible to define threshold values needed for a specific goal. Then using normal MIL-HDBK-17 procedures it is possible to define the required sample size

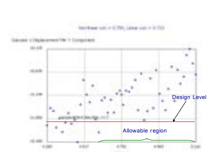


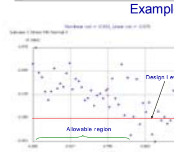
Dependency of the requirement 1 with material properties



Example of Small Structure (Stiffened panel)

Dependency of the requirement 2 with material properties





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