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D.O.E. about foam CF45 for pedestrian safety in car design

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A statistical approach based on the variance analysis allows to appraise the influence of the foam that cover ACEA leg impactors on the results of the tests required for the safety of the pedestrians in case of accident. This analysis is a part of a more complex DoE that analyse the difficulties when we simulate by FEM the impact pedestrian-car. In problematic that are complex and not linearly influenced by many factors even a numerical simulation could be improved and optimised by statistic techniques.

1. INTRODUCTION

Actual methodologies of calculus, in all the fields, are hugely based on the extaltation of the computer; it seems that all problem could be resolved by computer, so often the researcher don't analyse the nature of the problem. The results achieved, based on this convincement, are often inaccurate or even wrong and conflicting. On the other hand the theorists often "they despise" those whose efforts are oriented to the practise, then the efforts of the theorists result often sterile.

From here the need to create a bridge between theory and practice; this bridge is constituted from what today we call generically "soft computing," and that deal the theory of the uncertainty.

Marcyk say: "*Today, Computer Aided Engineering is sterile, purged of emotions and corrupted with false promises. The community of engineers is obligated to pretend respect to methods that often simply lack foundation. Those that not only see but also have vision, are witnessing an inflation in terms of number of flops, bytes and finite elements and a growing deficit in terms of new methodologies and ideas .Engineers, surprisingly, are not concerned about the degree of belief of their models*".

In effects the idea prevails that the problem could be resolved increasing the power of computers and then the level of detail of the simulations. With reference to the FEM, the term "mesh-man" was coined by idolaters of the computer.

Really, independently of the power of the computer, completely correct results for ideal models of real objects are not possible. Suffice it to think about the variability of the geometrical and mechanical characteristics of a simple pivot, to become convinced that just the computer could not give us satisfactory results.

If we analyse for example some kinds of foam, we note that they present a very complex structure, and we realise that it is difficult to build a physical model, and even more difficult to build a numerical model congruent with a tested foam.

More clinging results to the reality could get with statistic or fuzzy methodologies, or with methodologies however derived from the theory of the information that allows the best use of the information drawn from the experimental proofs or from the theoretical models that our potentiality allows us of build.

The layout of a DoE work plan allows then the extraction of information useful to the design also when we use numerical methodologies like FEM analysis. In this paper we show how this technique is applied when numerical simulations are used in place of experiments, for investigate the phenomenon impactor-car impact, particularly in the determination of the influence of the foam that dresses the Upper-leg impactor.

2. D.O.E. FOR THE PEDESTRIAN-CRASH SIMULATION

A new European norm, that fix procedures and levels for car-tests about pedestrian safety, was emanated with the purpose of reduce the mortality in the cases of accidents that they involve pedestrians and cars.

Particularly all the new car models must overcome severe tests that foresees the throwing of part of dummies, indicate as impactors, in specific points of the car to simulate the collision pedestrian-car and then to measure the strengths, decelerations and energies levels that they must be tolerabled by involved parts of the human body.

The simulation of the pedestrian-car collision requires that are available models of the car and of impactors "right" and meshed with elements of the "correct" dimension; that these impactors are "correctly" positioned over the car and launched with the "right" speed; that the materials of the models of car and impactors are characterised with the "opportune" mathematical model and that the parameters of such model are measured with "good precision”.

It is appropriate to wonder how we needs to be "right", "correct", "opportune" and "precise" and if it is really useful invest time and resources in the search of values that they could be not important for the precision of the simulation, and if it is really useful deepen the level of detail for all the variable that influence the phenomenon.

An experimental work plan for the determination of the more important parameters is obviously necessary. We had to realise a design of experiment to organise the experiments and the tests that we have to do to have goods results in accordance with instructions of the regulations. We can define a design of experiment like the following:

- Level 0: Recognition of and statement of the problem.
- Level 1: Choice of factors and levels to be varied in the experiment.
- Level 2: Data analysis.
- Level 3: Drawing up of D.O.E.

So we are going to analyse the statement of the problem to choice the interesting factors, that should be represented by materials of impactors and cars, by typology of mesh and by different possible points of impact, we should analyse results of experimental tests and results of simulation, then we will give some indications about general form that we have to use when we make experimental tests and simulation.

3. WHAT IS A EXPERIMENTAL DESIGN

The design choices are based on the knowledge that the designer possesses in systematic manner and by intuition (the so said experience). This knowledge can increase through "experiments" that they could underline what variables cause substantial alterations of the functionality of the system who is in phase of development. Unfortunately, above all when the knowledge is poor (and therefore when experiments are necessary), it is not clear what are the experiments and the variable on which we can act.

Design of experiment perform a indispensable tool to observe and identify the reasons for changes in the output response, when we assign same input instead other and these in consideration that the variables in a specific process are numerous, same of these controllable and other no (although we can consider same of these controllable for the purpose of test). The objectives of an experiment are the following:

- Determining which variables are most influential on the response.
- Determining the influent range of input of variability so that output is almost always near the desired nominal value.
- Determining the influent range of input of variability so that variability of output is small.
- Determining the influent range of input of variability so that the effects of uncontrollable changeable are small.

The objective in many cases may be to develop a robust process, that is a process affected minimally by external source of variability. By this way the product or process will be projected so that his performances are resistant for all font of noise, or rather the product continues to be satisfying also when the input characteristics and condition of ambient change.

3.1. Applications of experimental design

Experimental design methods have found broad application in many disciplines. In fact, we may view experimentation as part of scientific process and as one of the ways we learn about how systems or process work. Generally we learn through a series of activities in which we make conjectures about a process, perform experiments to generate data from the process, and then use the information from the experiment to establish new conjectures, which lead to new experiments, and so on.

Experimental design is a critically important tool in the engineering world for improving the performance of a manufacturing process. It also has extensive application in the development of new processes.

As well as to improve the production, to reduce the variability, the development time and the costs, an experimental design, (especially in the activities of design where we develop new products and improve the existents), allows to:

- Evaluate and compare basic design configurations.
- Evaluate material alterations
- Select design parameters so that the product will work well under a wide variety of field conditions, that is, so that the product is robust
- Determinate the key product design parameters that impact product performance.

3.2. Basic Principles

If an experiment is to be performed most efficiently it is indispensable to plan it, if there are more experiments to do, we have to plan all the experiments to make a cycle that is the only way to realize a complete and thorough design of experiment.

By the statistical design of experiment we refer to the process of planning the experiment so that appropriate data that can be analysed by statistical methods will be collected, by this way we can get valid results. When the problem involves data the are subject to experimental errors, statistical methodology is the only objective approach to analysis.

How we can see there are two essentials aspects to any experimental problem, the first one is the design of experiment, the other is the statistical analysis of data, obviously these two subjects are closely related.

There are three basic principles of experimental design that are *replication*, *randomisation* and *blocking*.

By replication we mean a common replication of the basic experiment. Replication has two important proprieties, first, it allows the experimenter to obtain an estimate of the experimental error. This estimate of error becomes a basic unit of measurement for determining whether observed differences in data are really statistically different. Second, if the simple mean is used to estimate the effect of a factor in the experiment, then replication permits the experiment to obtain a more precise estimate of this effect.

By randomisation we mean that both the allocation of the experimental material and the order in which the individual runs or trials of the experiment are to be performed are randomly determined. Statistical methods require that the observations be independently distributed random variables. By properly randomising the experiment we also assist in "averaging out" the effects of extraneous factors that may be present.

To use statistical approach in designing and analysing an experiment, it is necessary that everyone involved in the experiment have clear idea in advance of exactly what is to be studied, how that data are to be collected, and at least a qualitative understanding of how these data are to be analysed.

May be useful to follow some guidelines that we can resume in the following sentences:

- Recognition of and statement of the problem.
- Choice of factors and levels to be varied in the experiment.
- Selection of the response variable.
- Choice of experimental design.
- Performing the experiment.
- Data analysis.

4. THE REALIZED TESTS

As shown in the paragraph 2, the simulation of the collision pedestrian-car contains a notable series of elements of variability on which the car producers currently investigate in order to determine design criterions that take into account the limits imposed by the norms.

Respect of all the different variables, the study of the influence of the foam that dresses the upper-leg impactors on the phenomenon is presented in this paper, and particularly his mathematical model in a Finite Element software and therefore on the simulation of the phenomenon.

The kind of realized tests has been tells by necessity to study the behaviour of material in conditions near that of simulation. For the foam we have realized compression tests in low and mean velocity.

High speed compression tests, even if necessary, are very difficult to realise and are neglected in this study.

4.1. Tipology of samples

Tipology of samples that we have studied are two, the first is cubic and the second is cylindrical because the behaviour of these foams is influenced by the quantity of air that remains trapped in the tunnels. As well as different form we have studied, for the same reasons, samples whit same form but with different dimensions.

In the following Table.1 are reported the dimensions of studied samples:

Table 1
specimen dimensions

	Cubic		Cylindrical	
	thickness	25 mm	thickness	25 mm
Sample a	width	50 x 50 mm	Radius	35 mm
Sample b	width	30 x 30 mm	radius	30 mm

These test-tubes was compressed at different low speed, shown in Table.2, both for the cubic test-tubes and for those cylindrical using a load cell of 1kN because of the elevated strengths reached for deformations near to the unity, when the so-called packaging phenomenon happens.

Table 2
Test speeds

Test groups n.	1	2	3	4
Speed (m/s)	50	200	400	600

5. RESULTS OF TESTS TREATMENT

5.1. Fundamental problems of mathematical statistics

The mathematical laws of the theory of the probability are not a pure abstraction, deprived of physical sense, but they represent the mathematical expression of the regularities of the casual phenomenon of the nature, reproducible a large number of times.

To the base of a law of distribution of an uncertain variable there is an experiment; each study of *uncertain* phenomenon performed with direct or indirect methods of the theory of the probabilities is based on experimental data. Using the notions of event and his probability, of uncertain variable, of distribution law and of numerical characteristics, the theory of the probabilities allows to determine by theoretical way the probabilities of one event conditioned by the probability of other events, the laws of distribution and the numerical characteristics of other *uncertain* variable.

The indirect methods allow to economise time and money necessary for the experiment, without however exclude it. All studies, abstract and not, of the uncertain phenomenon have they origin in the experiment and in his observations.

The methods of recording, description and analysis of the statistic experimental data derived by the on a large scale continue observation of the casual phenomenon, according to the concrete problem to solve and to the volume of the available data, they could engage various forms.

The regularities observed in the casual phenomenon are as more exact and evident as bigger the number of statistic data is available. When we treat a large number of statistic data we have often the difficulty of determine the distribution laws for all the uncertain variables. Theoretically, when the number of proofs is sufficiently big, the regularities that are connected to these variable could be revealed with a random precision.

In the practises however, we have to treat a limited number of experimental data, so the results of the observations and they of the treatment always involve an uncertain element more or less evident. In this case we need to distinguish the constant, stable and own appearances of the real phenomenon, from those typically uncertain usually revealed in a relatively small number of observations, therefore the data inferred are not sufficiently big set of observations.

Obviously we need to require that, until when it is possible, the methodology of the treatment of the experimental data preserve the characteristics pulls of the phenomenon and abdicate to the inessential pulls.

5.2. Experimental results and probabilistic elaboration

We want now to analyse procedures that allow to examine and elaborate the result of n experiments. We have already seen like that it is necessary repeat more times the experiences related to each treatment in order to reduce the casual part and to evaluate the right variance to appreciate the reliability of the results.

Therefore we elaborate from the gotten data the information that we thought about get through the experiment and we evaluate their significance by means of the variance analysis.

We have realized an ample variance analysis about the foam essentially for the followings reasons:

- study of the effect on the results of the difference of form between the used test-tubes
- study of the effect on the results of the speed of deformation
- study of the effect on the results of the dimensional difference

This analysis was performed on the experimental data gotten from the proofs of compression (or rapid crushing) that we have realized on the foam test-tubes previously described. The available data refer to test-tubes of equal dimensions, of square and cylindrical form, subjected to different speed of compression. We need to remember that this paper will be dealt with proofs executed to compression speed decidedly lower than those to which the foam is really subjected and to which we make the computer simulation of the proofs.

In order to get a complete and common panorama for all the statistic analyses relative to this material, we have realized a scheme for define any fundamental footsteps to automatically predispose the data to analyse.

Initially we needs to effect a very accurate Data Entry: in fact errors introducing the data strongly jeopardize the results of the analysis. To this purpose one "they clean the data" from possible noises due to the data acquisition system of the proof tool; subsequently, paying attention to the setting of the measure tool, we split the data results that are deprived of physical meaning. Then, considered that to compare the curves we need to define some groups of analysis, we will define the values of deformation that will represent the " grouping variables" of the relative tensions to a date deformation and for a date speed of a determined test-tube.

The tension corresponding to each point of deformation is drawn through polynomial interpolation; since the massive structure of data and since for each test-tube and for each speed the points of deformation and the respective tensions change, the interpolation happens through elaboration to the calculator with polynomials of elevated degree and with elevated precision.

Figure 1 and 2 show elaborated results and corresponding variance.

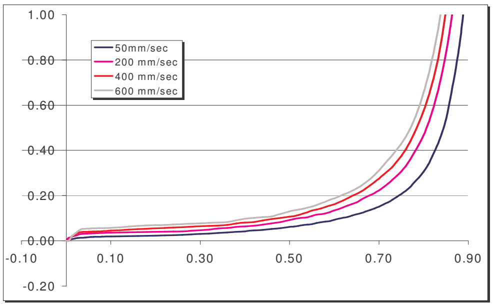

Figure 1. Foam tests results

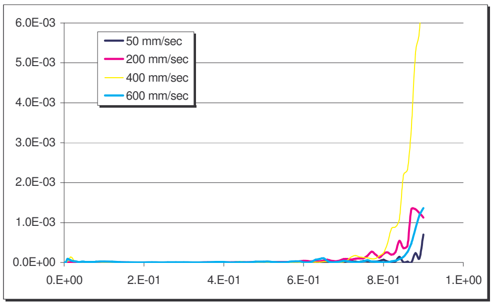

Figure 2. Variance v/s deformation

The selected values of deformation define the necessary groups for the analysis of the tension. They are selected realizing a kind of Blocking, operation that will also have repeated for the other types of test-tubes, and that drift from an attentive observation of the experimental curves. In effects it is clear that a statistical analysis in general and especially a variance analysis is so much more necessary and somehow interesting as better it is the disorder between the curves and consequently between the points of deformation. For this reason we have defined the points of deformation with a bigger density in the final part of the curve, where the dispersion increase of the points of the corresponding curves to a date abscissa. Once gotten the groups of the values of tension, an variance analysis is performed in the groups for which the experiment is relative to a not-varied Anova, as the term is unique and it is represented by different levels of speed and with a determined number of observations for each deformation.

6. CONCLUSIONS

It seem opportune underline some concepts that, even if known, they often escape to the operator because, when applied, these concepts appear suddenly difficult.
First we underline that each measure is accompanied by the uncertainty. The study of problems related to this uncertainty could be more or less complex and it depends on the purposes of the operator.

In the simpler cases, for instance a joint tree-hole, it is often sufficient to regulate the production on the base of the tolerances prescribed for a good working system. On what they are the specific causes that carry to the deviations for the product piece from the real dimensions to the nominal ones, often the operator is not interrogated.

Many problems concern instead quite the search of factors that influence a certain phenomenon; the techniques of the statistical analysis one or multi-varied and of the factorial analysis are then applied. Such techniques represent two appearances of only one discipline.

We could tell that while the technique based on the variance analysis tends to clarify the relationships between the independent variable and those dependent, the factorial analysis tends to "discovery" the so-called latent variables, that is those factors that influence the phenomenon but are not evident.

The now exposed considerations confirm how the analysis result depends on the common sense and also on culture and formation of the operator: without those would be easily fallen in coarse errors.

For instance, from the examination of a not very meaningful sample, formed of elements rich and with glasses, we can suppose the existence of a strong relationship between myopia and economic comfort, while the statistic relief show only the not incompatibility between myopia and comfort.

We observe moreover that it is not always easy to distinguish between independent variables and dependent variables.

Knowing the difficulties of the statistical approach but also the power of its methods, we have proceeded to the statistical analysis of the experimental results gotten from any proofs you correlate the problematic of the bump pedestrian-vehicle. We could have taken away the strong dependence of the values of the characteristics of the foam from the dimensions of the test-tubes and from the speed of deformation, and not only from the value of the deformation, while the form results less influential.

Yet it seems certain at least that the characteristics values of the CF45 are objective. But the uncertainty of the relief of such data is very bigger than how we gain from the measurements of other measures (lengths, weights, [etc].); this is because it is more complex

the structure in examination, and therefore more complex is the related qualitative model that we try to transform in quantitative model.
The uncertainty stays, but a statistical analysis conducted with wisdom could give the sufficient information and the necessary trust in the acquired results.

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