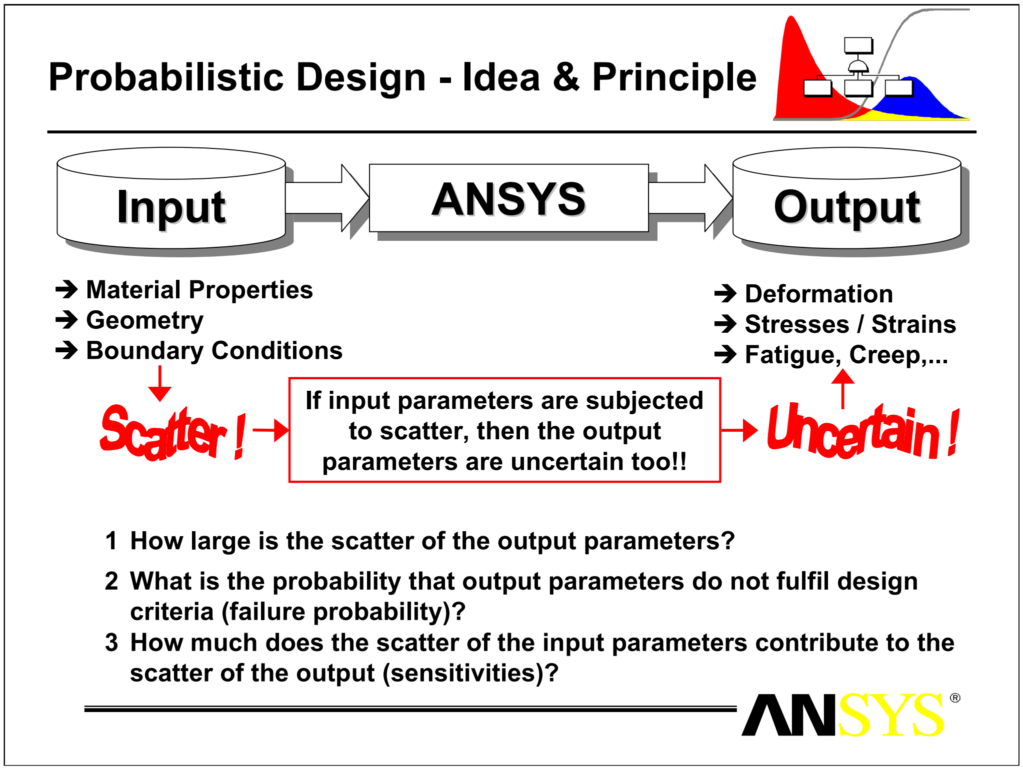

The idea of the slide is to illustrate the purpose of a probabilistic design tool:

If we analyze a component then we start out with the fact that the component is described by a certain set of input parameters, namely material properties, geometric extensions of the component and boundary condition that describe how the component is loaded and where and how it is fixed. Then the component is analyzed and as result we can look at its deformation, review the stresses and strains. In addition, we can assess its fatigue lifetime or its creep behavior and such.

The idea behind probabilistic design starts with the observation that as a matter of fact the input parameters are subjected to scatter. As a direct consequence we have to face the fact that the output parameters are uncertain as well.

A probabilistic design tool provides answers to the following questions that are important in this situation:

First: If the input parameters do scatter then we want to know how large is the scatter of the output parameters. In other words we want to quantify the uncertainty of the output parameters.

Second: If the output parameters are uncertain then we want to know how large the probability is that an output parameter by chance does not meet some design criteria. I. e. we want to know how reliable the component is.

Third: If the output parameters are uncertain then we want to know which parameters on the input side contribute the most to the uncertainty of the output parameter. Knowing this we will be able to tackle the “evil” drivers efficiently and improve the reliability of the component.

Probabilistic Design - Benefits

Deterministic Analysis:

- Only provides a YES/NO answer.
- Safety margins are piled up "blindly" (worst material, maximum load, … worst case) => Leads to costly over-design
- Only "as planned", "as is" or the worst design
- Sensitivities do not take possibilities into account
- Sensitivities do not take interactions between input variables into account (second order cross terms)

Probabilistic Analysis:

- Provides a probability and reliability (design for reliability)
- Takes uncertainties into account in a realistic fashion => This is closer to reality => Over-design is avoided
- "Tolerance stack-up" included (design for manufacturability)
- Range/width of scatter is "built-in" into probabilistic sensitivities
- Interactions between input variables are inherently taken care of

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This slide shows a comparison between the deterministic and probabilistic approaches:

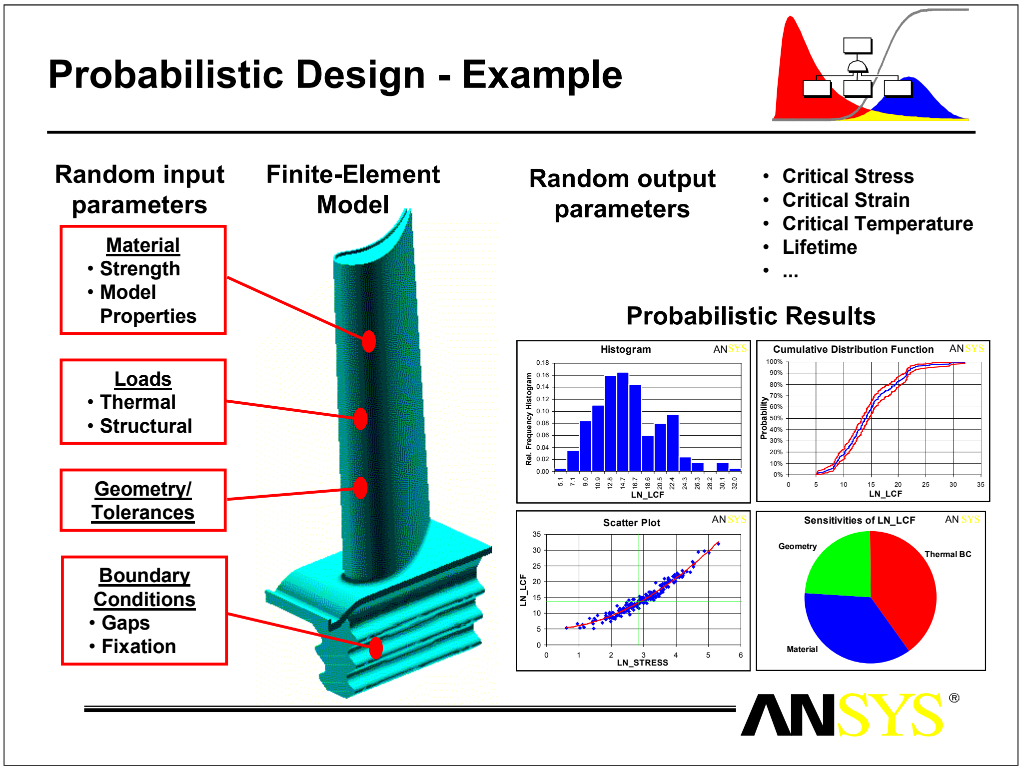
• Deterministic analyses can only provide a binary information derived from the single point solution (the analyzed component is OK or not). Probabilistic methods provide also a probability for the solutions, e.g. a "design for reliability" is possible.

• In deterministic analyses uncertainties are taken into account by safety margins that are stacked up blindly. I.e. we are designing for a component with the weakest geometry and worst material properties subjected to highest load. Such a component is literally not existing. This leads to an expensive over-design. In PDS the uncertainties are taken into account in the way they appear in nature. This way an over-design is avoided, which can safe a lot of money.

• Deterministic Methods only assess one specific design, whereas PDS takes the deviations from that design into account that could lead to a tolerance stack-up. Taking this into account enables a smarter design-for-manufacturability, which also can safe a lot of money.

• Deterministic models have no concept of the deviations that are possible apart from the "as planned" design. In PDS this is inherently taken into account.

• Also in the deterministic approach sensitivities can be evaluated. But this is done by applying a plus and minus Delta-value to an input parameter while keeping all others constant. This way interactions cannot be covered. Interactions lead to the fact that a variation of two parameters at the same time can have a much larger effect then the combined effect of the variation of the two individual parameters if varied one at a time. According to experience these interaction are important for about 20% of all applications. This is inherently taken into account in probabilistic sensitivities.



The slide picks up the structure of the first slide again where some input parameters by means of a FE model are transferred to some output parameters. The slide illustrates a few graphical probabilistic results that can be expected from the PDS:

- top left: The histogram of an output parameter illustrated how large the scatter of that output parameter is
- top right: The cumulative distribution function illustrates the probabilities that output parameter exceeds or remains below a certain critical or admissible limit
- bottom left: A scatter plot illustrates how two output parameters (or an output and an input parameter) are correlated with each other, which is a measure for the sensitivities
- bottom right: The sensitivity graph directly illustrates how much the input parameters effect individual output parameters