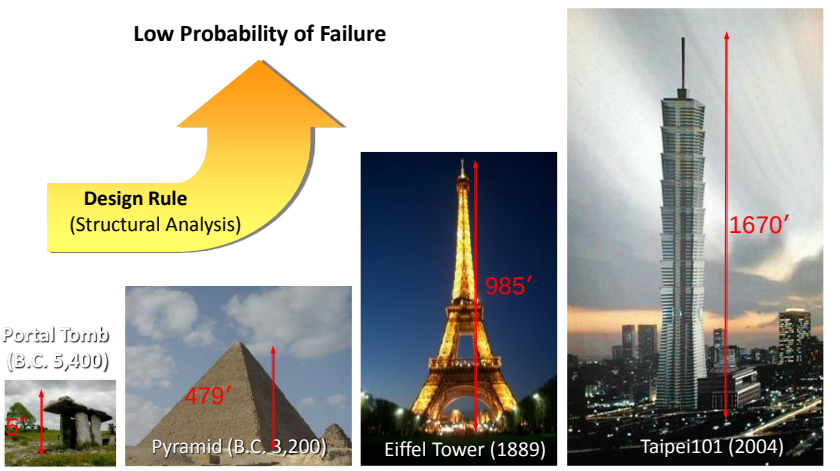
Intro: Structural Reliability

Center of Excellence for Product Reliability and Optimization

Based on Prof. Ramana Grandhi's Lecture

The Magic of Design



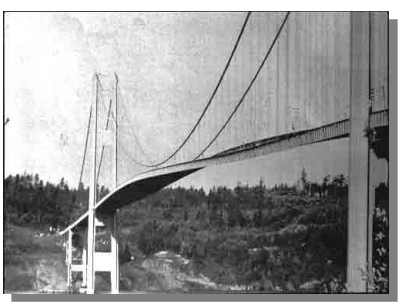
Life, Full of Uncertainties

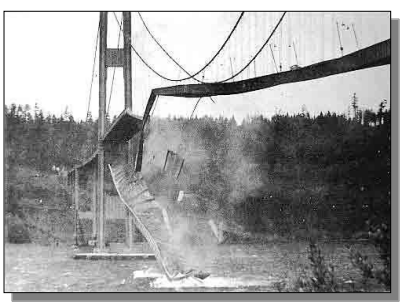
Space Shuttle Catastrophes, USA, 1986 and 2003: Unforeseen variations of system conditions cause accidents of two shuttles (Challenger and Columbia)

3

Life, Full of Uncertainties (Cntd.)

Collapse of the Tacoma Narrow Bridge, USA, 1940: Turbulent winds cause torsional vibrations





4

Life, Full of Uncertainties (Cntd.)

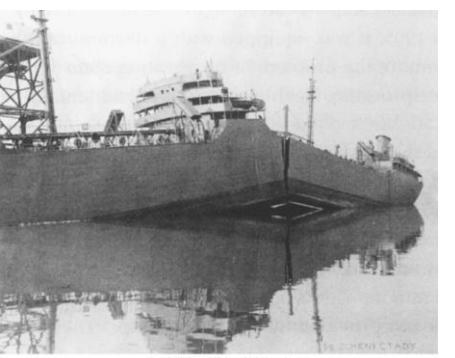
Risk of Aging Aircraft, Aloha Airlines Flight 243 (19-year-old aircraft), Hawaii, 1988: Undetected fatigue causes critical damage

5

Life, Full of Uncertainties (Cntd.)

Mississippi bridge I-35W failure

S.S. *Schenectady* T-2 tanker broken into two



Example of Random Variables (Cntd.)

The life of a bulb, the arrival time of the next bus at a stop: these are examples of random variables that are encountered in everyday life.

7

Representative Risk of Death

Activity/Cause	Number of Deaths Per Year Per 10^6 Persons
Air travel	9
Rail travel	4
Water transport	9
Motor vehicles	300
Poison	20
Lightning	0.5
Fires	40
Machinery	10
Structural failures	0.2

8

Sources of Uncertainties

- **Uncertainty in the design process can arise from many sources:**
  - Inaccurate parameters
  - Unmodeled physics
  - Numerical errors
  - Uncertain operating conditions
  - Disagreement among model responses
- **It is crucial to be able to quantify this uncertainty to obtain accurate estimates of system performance and reliability**

9

Design Under Uncertainties

Manufacturing

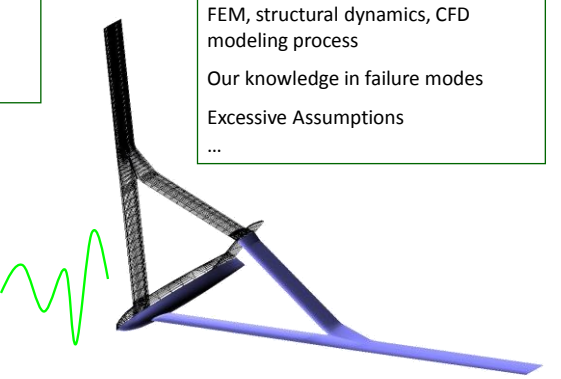
Material properties
Geometric properties
Welding, Assembling process
…

Simulation

Boundary conditions
FEM, structural dynamics, CFD modeling process
Our knowledge in failure modes
Excessive Assumptions
…

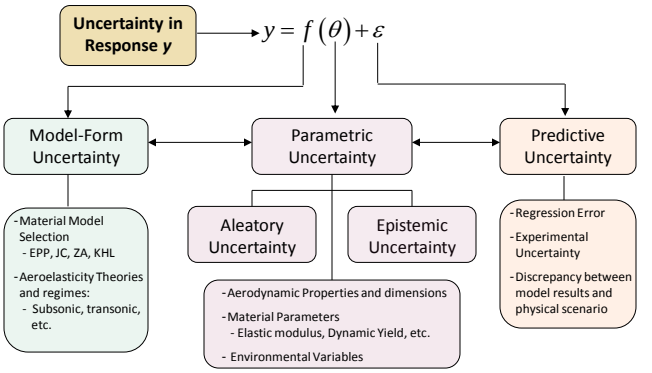
Flight Conditions

Random gust load
Different gravity factors
Human factors in flight
Required performance
Flight control system
…



10

Uncertainty Breakdown

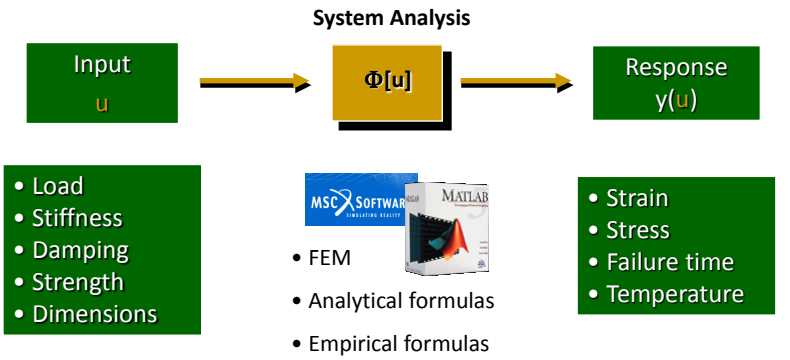


11

Overview of Uncertainty Quantification

12

Deterministic Analysis



The simulation of a single design point is extremely unrealistic when we attempt to identify the complete information of systems under varying loads and material properties.

Deterministic Analysis with Safety Factor

Safety Factor (Factor of Safety)

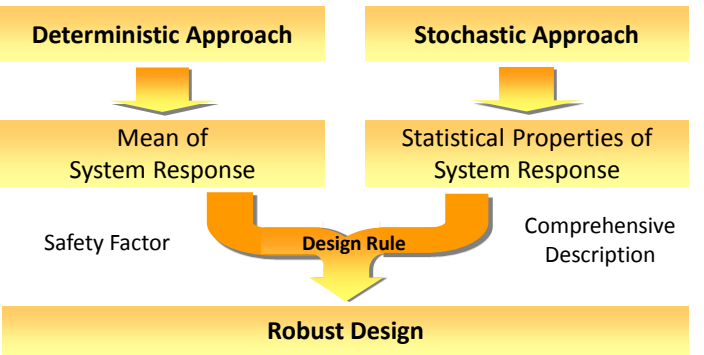
provides a design margin over the theoretical design capacity to allow for uncertainty in the design process

$$F = \frac{R}{S}$$

where R is the resistance and S is the capacity or loading of the system

The selection of the appropriate safety factor in design of components is essentially a compromise between the associated additional cost and weight and the benefit of increased safety or reliability

If it Works, Make It Better

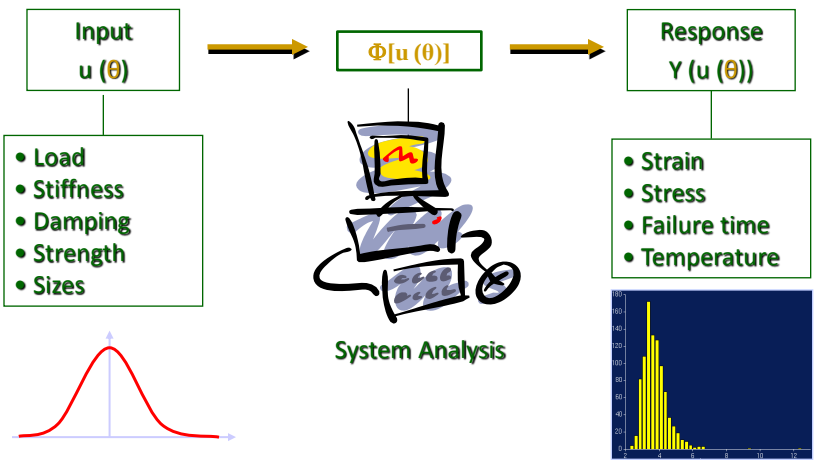


Both the resistance R and load S of the safety factor are random variables

➔ When the scatter in the variables is considered, the safety factor could potentially be less than unity

15

Stochastic Analysis



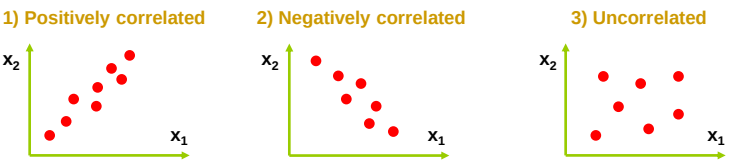
16

Stochastic Analysis

Stochastic analysis is a mathematical process involving a randomly determined sequence of observations, each of which is considered as a sample of one element from a probability distribution

Components of Stochastic Analysis :

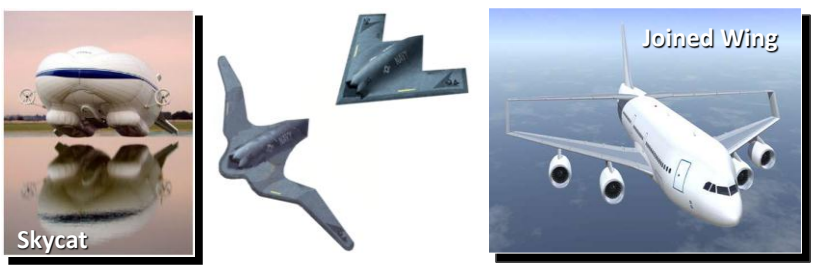
- Random Variable: Measurable values in probability space associated with events of experiments
- Probabilistic Distribution: Indicates a relative probability of observing each random variable
- Covariance (not independent):



When is Stochastic Analysis Useful ?

When we have unconventional designs:

- There is little relevant data with unconventional designs
- Difficult to estimate risks of new technology or design concepts
  - Appropriate understanding and treatment of uncertainty in the design process is essential for safe and efficient decisions



When is Stochastic Analysis Useful ?

When there are large variation of design variables and system properties:

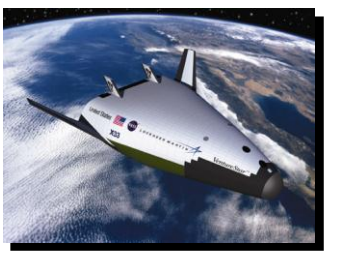
- Real world is highly variable
  - Significant variability in fatigue crack growth properties is possible for different batches of 2024-T3 Aluminum (NASA Report, 1988)
- Modelers often try to present results of "best-case / worst-case" scenario or averaged properties
  - Lack the mathematical soundness of applying statistical principles to account for model input parameter variability

19

When is Stochastic Analysis Useful ?

When fair safety is not good enough:

For people in spaceships, "survival" should be taken very seriously



Deterministic Analysis

↓

Mean of Structural Response

↓ **Safety factor**

Safe Design

Do not completely account for the random nature of most inputs

20

When is Stochastic Analysis Useful ?

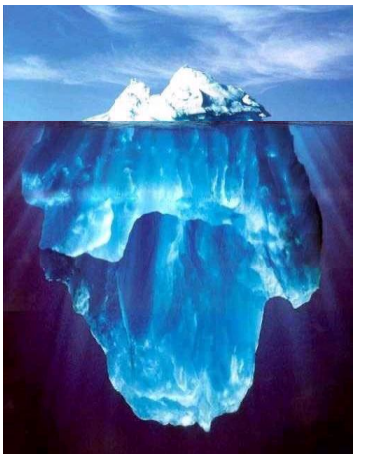
Stochastic Analysis

↓

Statistical Results of Structural Response

↓ Comprehensive Picture

Robust Design



Advantages of Stochastic Analysis

Why to quantify uncertainty ?

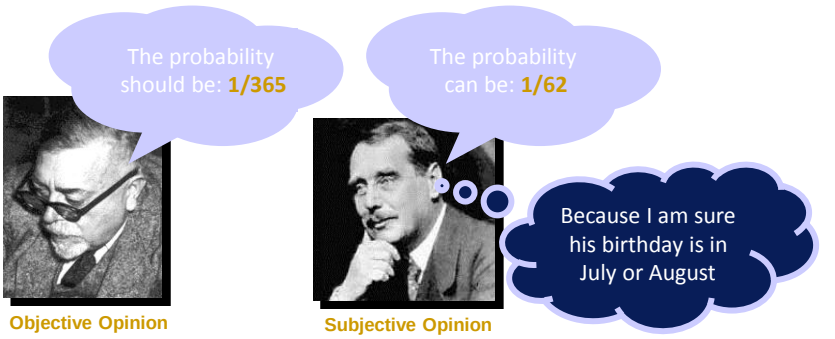
- Uncertainty is inevitable or sometimes foreseeable (bounded)
- Appropriate understanding of uncertainty is essential for safe and efficient design
- There is little relevant data with unconventional designs

Advantages

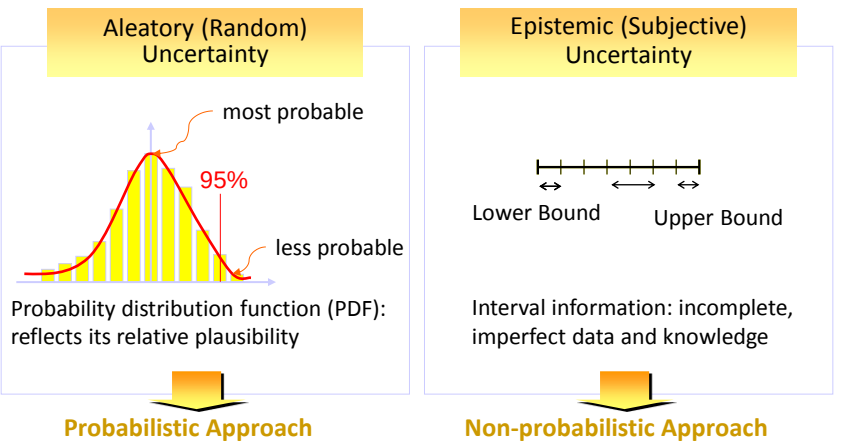
- More comprehensive picture for safe designs
- Better ability to detect when a structural system is staying outside the normal limits of uncertainty
- Analysts are able to quantify their confidence in performance estimates
- Risk informed designs / decisions

Representation of Uncertainty

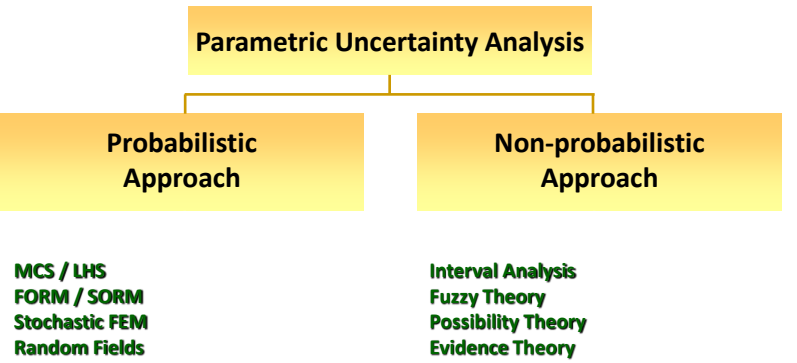
What is the probability of that a selected person has a birthday on July 4th?



Representation of Parametric Uncertainty



Parametric Uncertainty Analysis Categories



UQ Using Probability Theory