Reliability Analysis of an Aeroplane Wing

Project Team

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Objective

To explore a uncertainties quantification topic at greater depth for steady and unsteady problems in any field of engineering, using approaches, such as Monte Carlo Simulations and Hasofer-Lind-Rackwitz-Fiessler method for a correlated random variables.

Approach

- Define an engineering problem for reliability analysis
- Defining the random variables and their distributions
- CAD design of Aeroplane wing
- FE analysis using ANSYS Workbench
- Formulate a non-linear performance function using function approximation
- Computing Reliability using MCS and HL-RF

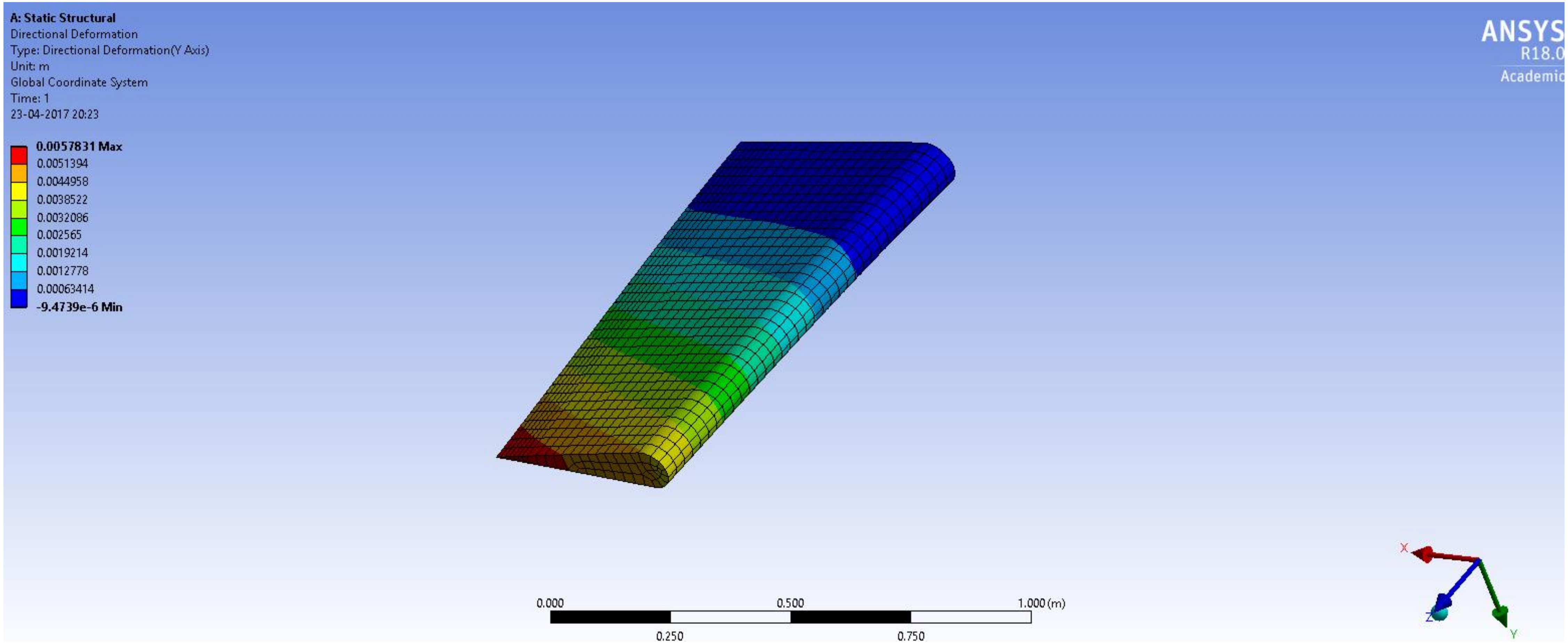
Random Variables

Variable	Mean	Distribution	COV
Length of wing (x1)	1200 mm	Normal	.1
Thickness of wing (x2)	103mm	Log normal	.1
Load (x3)	54000N	Uniform	.1

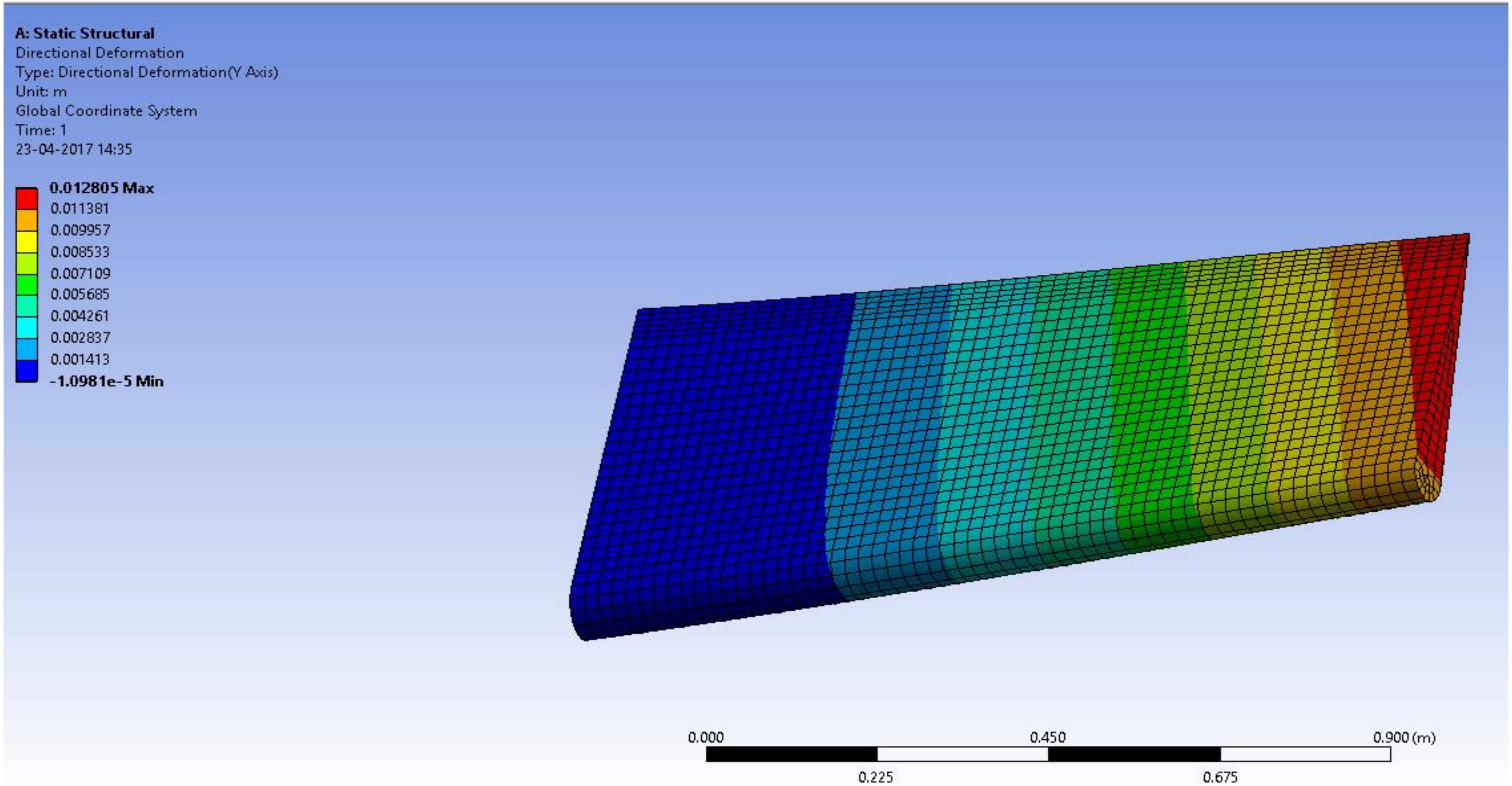
Finite Element Modeling

- The Aeroplane wing model was built using SolidWorks.
- The model was then imported to ANSYS Workbench.
- The FE meshing on the wing was then created and simulated.
- The loads and boundary conditions were prescribed and solved for deformation and stress.
- The Von-Misses stresses and Deflection were recorded from the simulation.

Finite Element Modeling - Results



Finite Element Modeling - Results



Two-point Adaptive Nonlinear Approximation

- TANA is a first order Taylor series expansion at point X_2
- The general expression for TANA:
  - $g_t(X) = g(X_2) + \frac{1}{r}\sum_{i=1}^{n}(x_i^{1-r} * \left(x_i^r - x_{i,2}^r\right) * \left(\frac{\partial g}{\partial x}\right)_{X_2})$
- Two points X_1 and X_2 are chosen, X_1 -Previous point, X_2 -Current point;
- $g_t(X) = g(X_2) + \frac{1}{r}\left(L_2^{1-r} * (L^r - L_2^r) * \frac{\partial g}{\partial L}_{X2}) + (P_2^{1-r} * (P^r - P_2^r) * \frac{\partial g}{\partial P}_{X2}) + (t_2^{1-r} * (t^r - t_2^r) * \frac{\partial g}{\partial t}_{X2})\right)$
- There are 3 unknowns in this particular problem (n=3).
- Where P = load, t = thickness, L = length;

TANA (Contd.)

- The previous and current points chosen as:
- X_1 = [1000, 45000, 90];
- X_2 = [1200, 54000, 103];
- Using these two points for length, thickness and load the gradient is calculated using numerical methods (Numerical Difference methods)

Gradient Calculations

- The gradients are evaluated at the point X_2.

$$\frac{\partial g}{\partial X} = \frac{g(X+\Delta X) - g(X)}{\Delta X}$$

Gradient Calculations	Numerical Value
$g(X_1)$	225.537
$g(X_2)$	200.196
$\frac{\partial g}{\partial L}$	-0.2422
$\frac{\partial g}{\partial P}$	-1.11e-04
$\frac{\partial g}{\partial t}$	-2.1775

Final Function Approximation

- Implementing the above algorithm in MATLAB, and using the gradient calculations, the final function approximation that will be used to test reliability is:

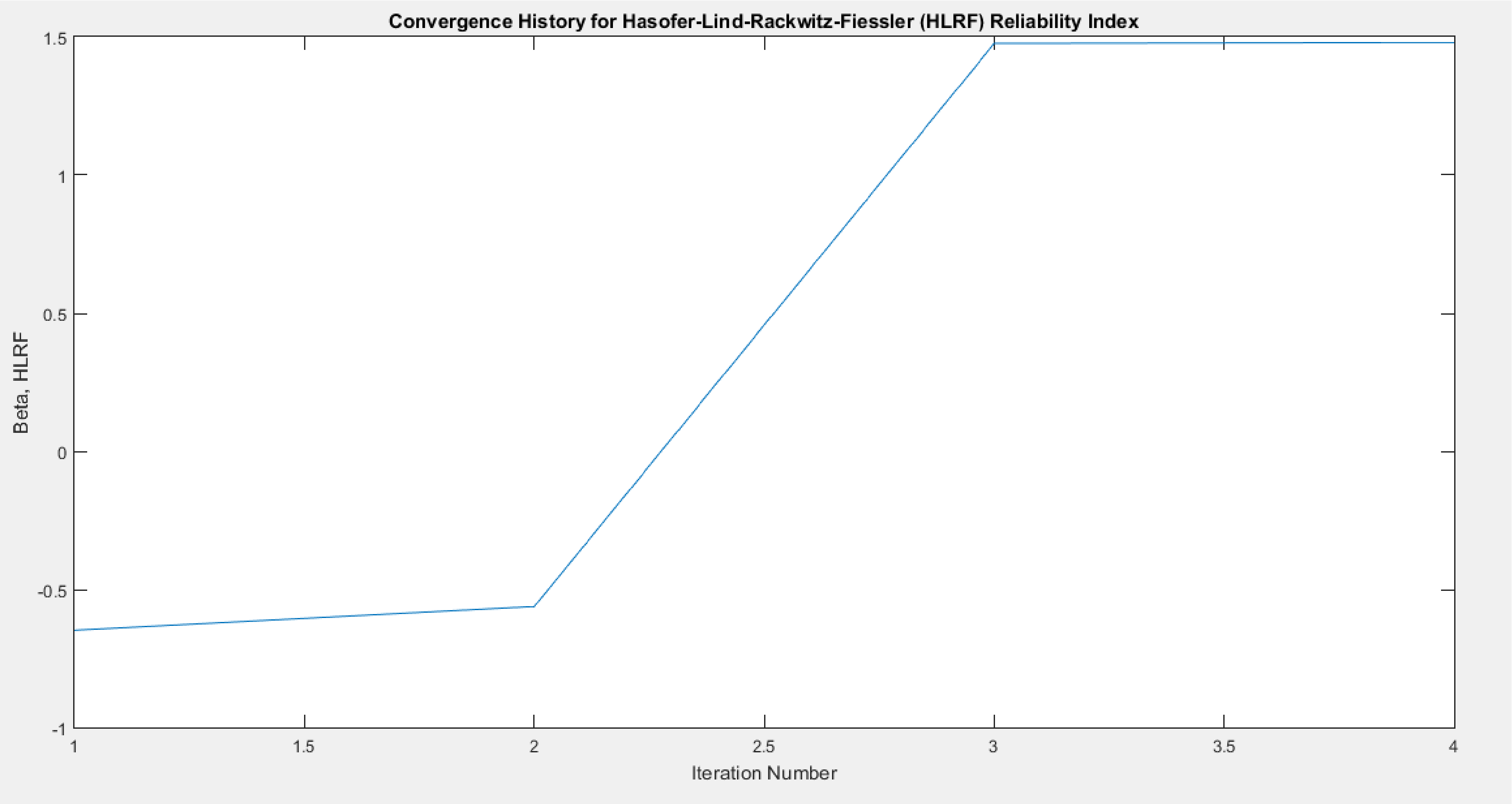
$$\mathbf{G} = \mathbf{226.8} - \mathbf{3.083} * \mathbf{10^{-6}} - \mathbf{60} * \boldsymbol{L}^{\mathbf{19.71}} - \mathbf{1.669} * \mathbf{10^{-6}} * \boldsymbol{P}^{\mathbf{19.71}} - \mathbf{2.443} * \mathbf{10^{-6}} * \boldsymbol{t}^{\mathbf{19.71}}$$

Testing Reliability using HL-RF

- Using the function obtained from TANA, the reliability of the wing is tested for a set of correlated non-normal random variables using Hasofer-Lind-Rackwitz-Fiessler method.
- In the RF algorithm of HL-RF method, the non-normal random variables are converted to their equivalent normal variables.
- The variables taken were correlated, and the reliability testing was done in MATLAB and the package was built to handle correlated /uncorrelated, normal/non-normal distributions.

Results from HL-RF

- The value of β converges after **4** iterations and the convergence plot is shown below:



Results from HL-RF

Parameter	Matlab Package
BetaFOSM	3.09
Reliablity	0.999
Failure Probability	0.001
Beta_HLRF	1.4796 **(after 4 iterations)**
Reliablity	0.9305
Failure Probability	0.0695

Varying statistics in HL-RF

Decreasing mean value by 20%

Parameter	Matlab Package
BetaFOSM	2.028
Reliablity	0.9787
Failure Probability	0.0213
Beta_HL	4.405
Reliablity	0.9999
Failure Probability	0.0001

Increasing mean value by 20%

Parameter	Matlab Package
BetaFOSM	-0.6806
Reliablity	0.2482
Failure Probability	0.7518
Beta_HL	1.228
Reliablity	0.8902
Failure Probability	0.1098

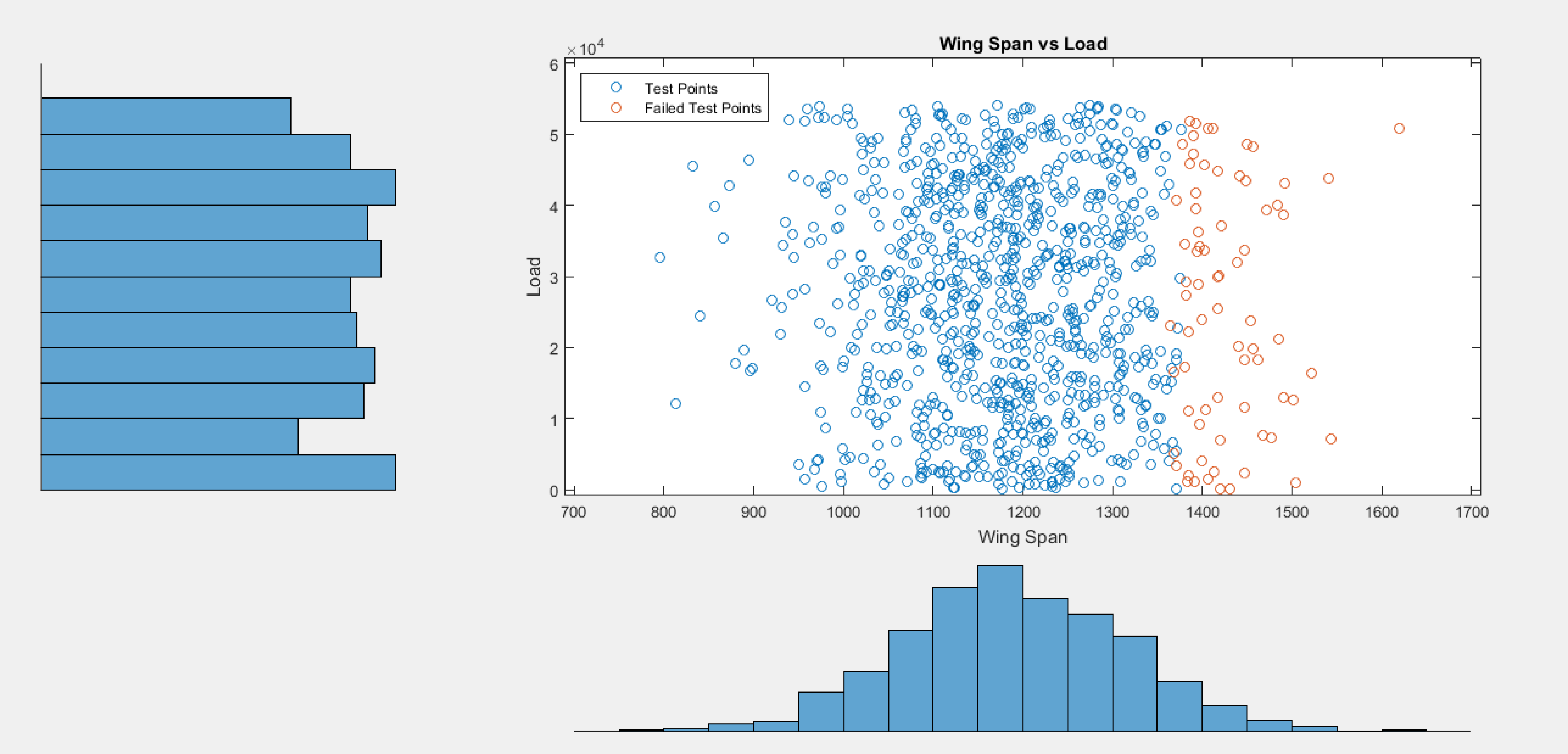
Reliability using Monte Carlo Simulation

- Monte Carlo simulations are done assuming for both correlated and non-correlated random variables
- Monte Carlo simulation is run for a 1000 samples
- The decorrelation for correlated variables are done using method of linear transformation and cholesky decomposition.

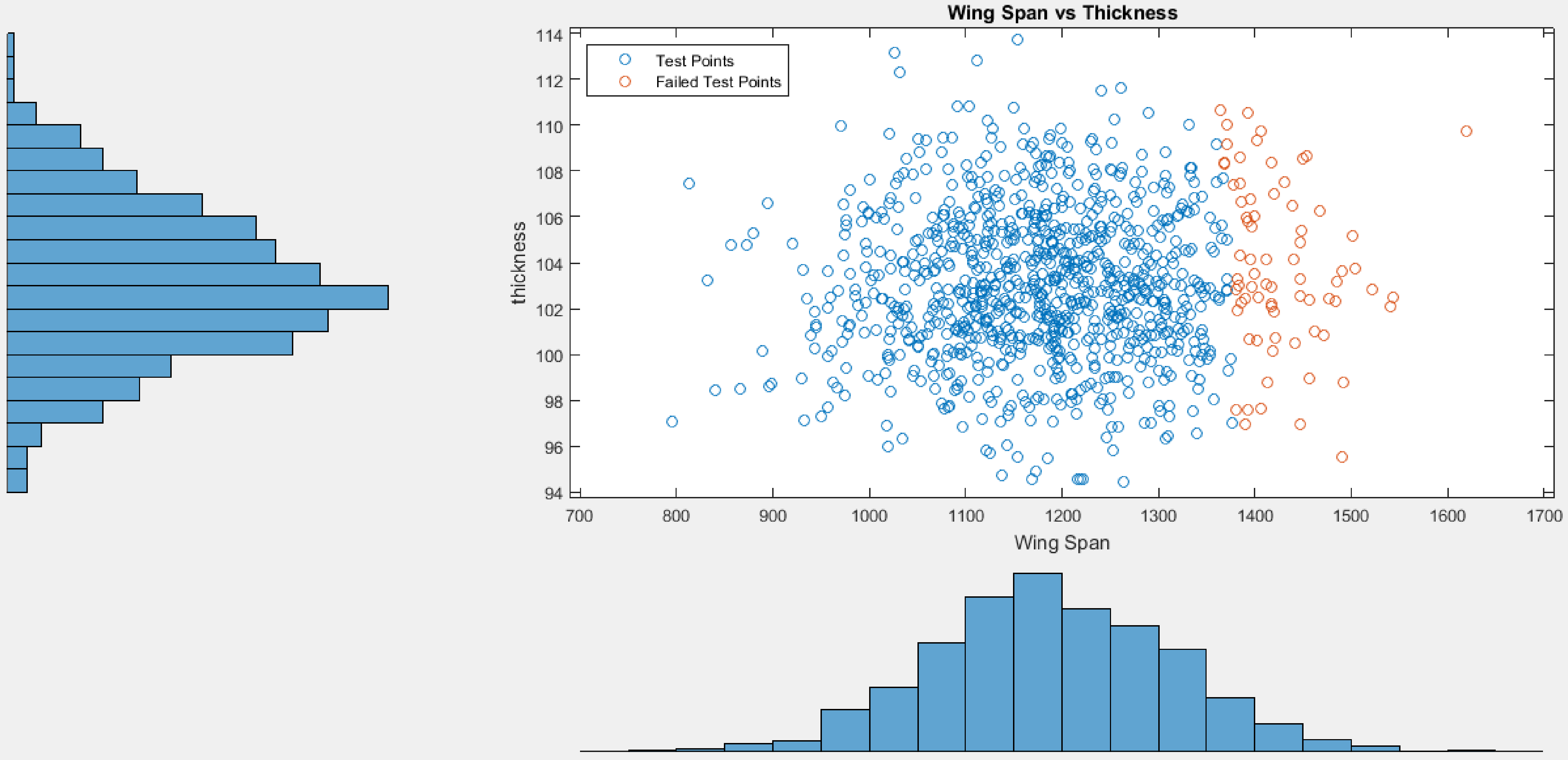
Results from MCS

Parameter	Matlab Package
Reliablity	0.93
Failure Probability	0.069

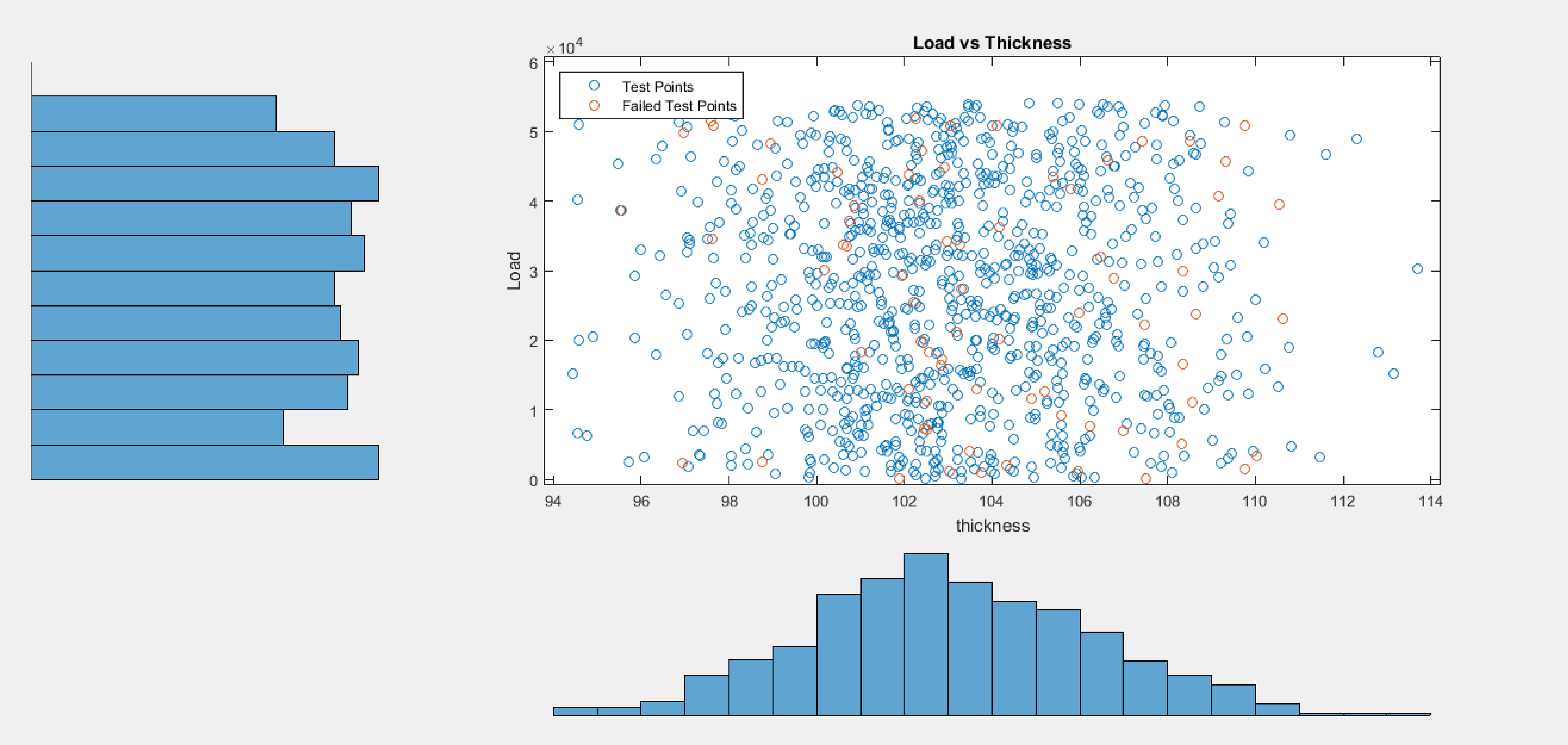
Results from MCS



Results from MCS



Results from MCS



Comparison of two methods

- The reliability computed using both methods is MCS