Uncertainty Quantification in Computational Fluid-Structure Interaction

- A Multi Level Monte Carlo (MLMC) implementation

Anoop Kodakkal *

*Chair of Structural Analysis, Technical University Munich

Abstract:

Deterministic computational modeling and numerical simulation is widely used as a method to tackle structural engineering problem. Unlike a deterministic analysis, a stochastic analysis takes into consideration various uncertainties in structural parameters, boundary / initial condition, loading etc to make a realistic prediction. Uncertainty quantification for complex and expensive problems like of Fluid-Structure Interaction (FSI) using Monte Carlo (MC) simulation method becomes computationally challenging or even infeasible in many cases. Multi Level Monte Carlo (MLMC) method is an improvement to MC method where the sampling is done from different levels (mesh sizes) of the same quantity of Interest(QoI). Here, in this poster the efficacy of MLMC for a fluid problem is presented with the outlook of using it for an expensive FSI simulation.

Motivation:

•Slender structure subjected to uncrtain wind loads

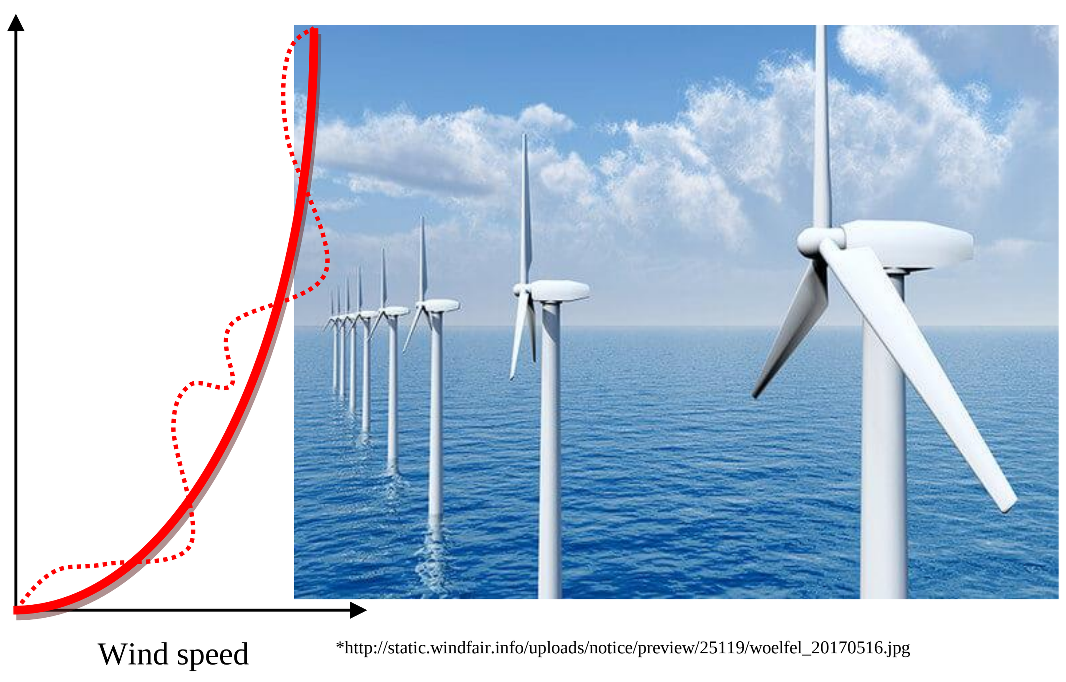

Fig 01 : Offshore wind mill tower under uncertain wind loads

Fluid-Strcture Interaction(FSI):

• For slender structure it is important to consider the mutual effects of fluid on structure and vice versa for an accurate prediction of reality.

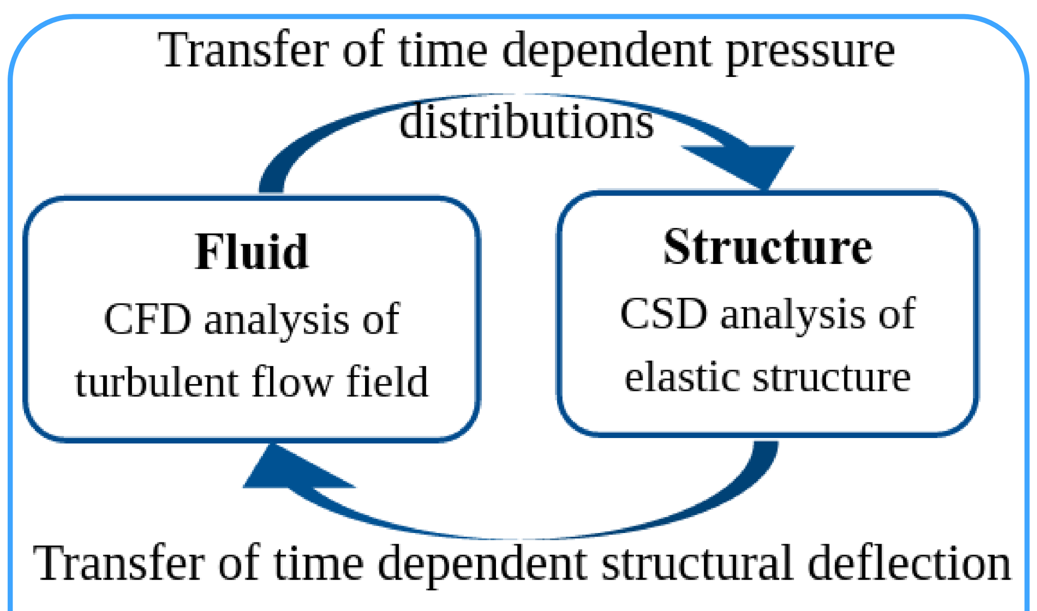

Fig 02 : Partitioned FSI workflow

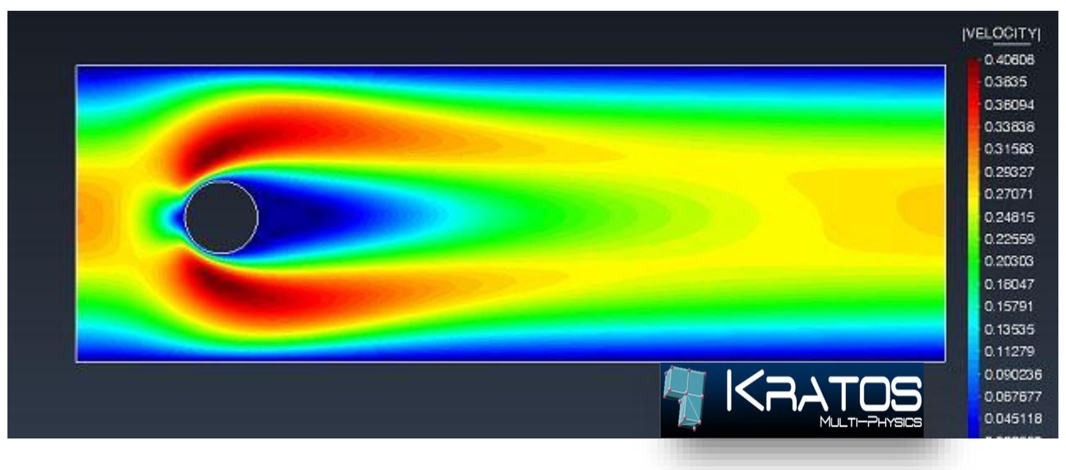

Fig 03 : Turek FSI benchmark [1]

Multi-chllenges:

UQ in FSI has to face with the following challenges

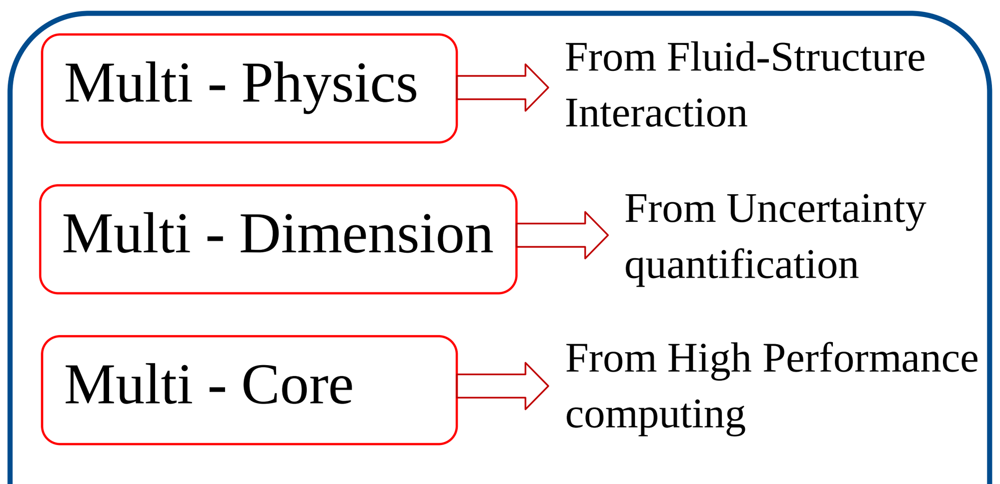

Fig 04 : Multi challenges for UQ in FSI and their sources

Multi level Monte Carlo Method:

MC method, based on the sampling from the input distribution and evaluating the QoI at each of the sampling points are the most commonly used approach. However, these becomes challenging if the individual evaluations are expensive.

MC estimate is

$$E[P] = N^{-1}\sum_{n=1}^{N} P(w^{(n)})$$

in **MLMC**

• There are different approximations (levels) for the same QoI in MLMC setup.

• The method is based on evaluting more samples at cheap coarse mesh and less no. of evalutions at expensive fine mesh

• The variance is minimized for a fixed cost by choosing the number of samples in each levels.

The unbiased MLMC estimator is

$$E[P_L] = E[P_0] + \sum_{l=1}^{L} E[P_l - P_{l-1}]$$

1.Start with L =2 and No samples on l 0,1,2
2.**While** extra samples needed
3. evaluate extra samples on each level
4. compute/update estimates for V*l*
5. Define optimal N*l*
6. Test weak convergence
7. If not converged add new level
8.**end While**

Algorithm 01 : MLMC algorithm [2]

Problem description:

Uncetain parameters :

Inlet velocity magnitude

Fluid material property – kinematic viscosity and density

Results:

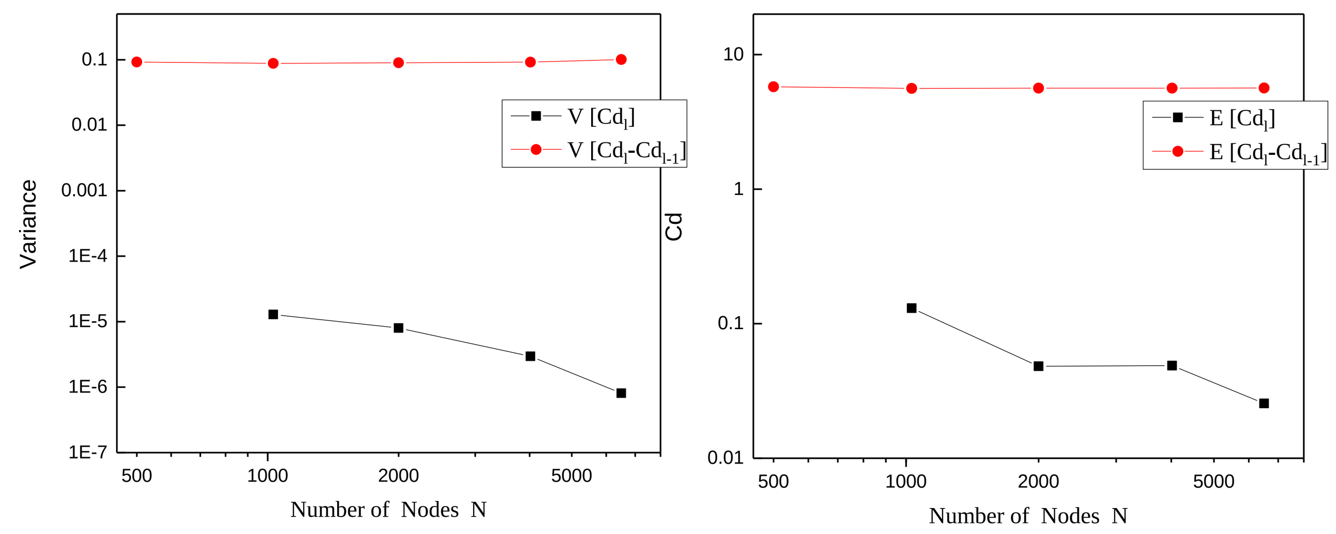

Fig 04 : reduction in variance over levels

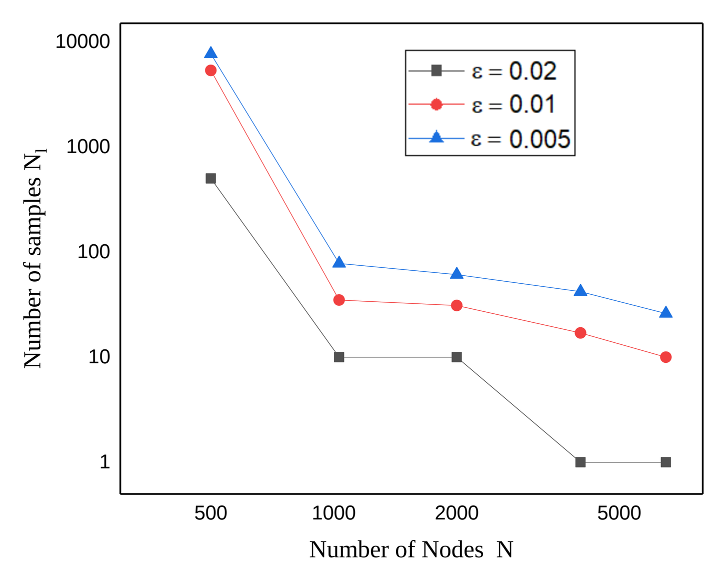

Fig 05 : Number of model evaluations in different levels in MLMC. The number of nodes are doubled in subsequent levels

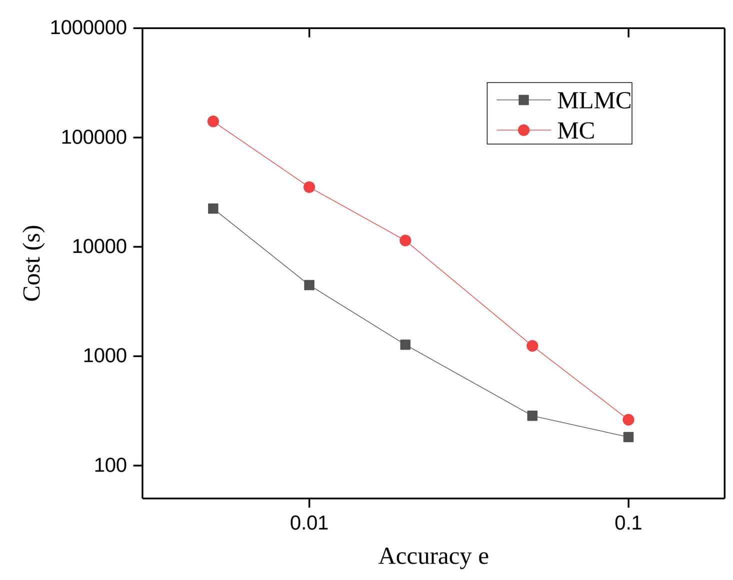

Fig 06 :Comparison of cost with MC

ε = 0.001	Cost factor	Estimator - Cd
MLMC	1	5.6291
MC	6.74	5.6174

Conclusion:

MLMC is found to be an efficient tool with potential for UQ in FSI

Acknowledgement:

DAAD Deutscher Akademischer Austausch Dienst German Academic Exchange Service

References:

[1] Turek S. and Hron J. ; 2006

[2] Giles MB; Acta Numerica : 2015

Contact information:

Anoop Kodakkal

anoop.kodakkal@tum.de