論文 / 著書情報
Article / Book Information

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Title(English)	Simulation of Fluid Dynamics with Uncertainty Based on Polynomial Chaos Expansion
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Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	機械 機械	系 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of （ 工学 ）
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

With the increasing usage of computational fluid dynamics (CFD), validating the CFD system; comparison of error and uncertainty between computation solutions and experimental data, became necessary. Compared to the studies on errors and uncertainties in experimental data, the errors and uncertainties in numerical simulation systems are not adequately investigated and remain unclear. Especially, quantitatively evaluating uncertainties in initial/boundary conditions and model parameter could not be attained directly from conventional studies of the numerical schemes or deterministic simulations. One of the effective approaches to analyze errors and uncertainties in the CFD system is polynomial chaos expansion (PCE) representing statistic characteristics of random variables as a series of orthogonal polynomial basis and the coefficients of each polynomial basis.
In this thesis, a series of study has been conducted to quantify the effects of uncertainties inherent in CFD simulations, as well as to utilize the quantified uncertainty characteristics of the simulation systems to enhance the application of CFD simulation for real-case fluid phenomena.

Chapter 1 introduces the background of error and uncertainty in the CFD system. Importance of considering error and uncertainty is addressed via introducing the standards of validation of CFD systems. With the introduced standard concepts, the definition of error and uncertainty as the standard is explained, and the definition of uncertainty for this thesis is clarified. With this definition, the concept of simulation of fluid dynamics with uncertainty is explicitly explained. Then we state the motivation and objectives of this thesis.

Chapter 2 explains the PCE; an orthogonal decomposition of probability space with polynomials in terms of random variables to represent the statistic characteristics of dynamic systems. PCE formulations for Burgers equation have been developed using two representative approaches, i.e., stochastic Galerkin method and stochastic collocation method. Based on the resulting formulations in the form of a linear matrix system, the dimensionality problem of the stochastic Galerkin method is addressed, and the relative benefit of stochastic collocation method is clarified. Numerical simulation of the stochastic Burgers equation is performed with each introduced stochastic methods, and the effectiveness of the PCE methodology was confirmed. For the selection of numerical quadrature used in the stochastic collocation method, convergence ratio of the Gauss-Legendre and the Clenshaw-Curtis quadrature were compared with numerical tests with different numerical quadrature and PCE reconstructions using different functions. The advantage the Clenshaw-Curtis quadrature is verified for the PCE reconstruction.

In chapter 3, the effect of the density uncertainty on the four representative shock-flat interface interaction (SFI) and two representative shock-bubble interaction (SBI) are quantitatively evaluated. The density is modeled as a random variable with the Gaussian distribution and represented as Hermite chaos using PCE, and their effects on the interaction between shock and interfacial multiphase are attained using stochastic collocation method. Effects of the density uncertainty on each flow structure generated from the interactions have been quantitatively clarified. It is also observed from these numerical experiments that there exist some insensitive regions in the solution domain where the density uncertainty does not significantly affect the numerical solution.

In chapter 4, the statistic information attained from the quantified results for the multi-scale wind forecast model is used to find out the critical parameter for improving the forecasting results. A multi-scale wind forecast model has been developed by combining the mesoscale weather research and forecast (WRF) model and the microscale CFD model OpenFOAM through a one coupling scheme of the wind profile. The

uncertainties in the coupling scheme and the turbulence model of OpenFOAM have been quantified by the PCE method. It is found that the effect of uncertainty in the coupling scheme for wind profile is much more significant in comparison with those turbulent parameters.

In the last part of this thesis, a PCE based data assimilation method using a surrogate PCE model constructed from the stochastic collocation method was developed. In this method, simulation input and output is represented with the PCE representation, respectively, and the gradients of PCE coefficients of the input and output with respect to the ransom variable is explicitly attained using the surrogate PCE model based on the orthogonal polynomial. With the gradients of the PCE coefficients, the PCE coefficients of the input can be estimated from those of the output, which is available from experimental data. This method has been applied to identify the inlet pressure of a pneumatic throttle system using the experimental measurement of the outlet mass flow rate. The numerical results agree well with the measured inlet pressure regarding the distribution of probability density function and exhibit a promising estimation within the IQR box range.

Chapter 6 gives a summary of this thesis and points out the major contribution of the current study. Finally, we also include some directions for further study. In the presented thesis, as summarized above, the development of a simulation system of fluid dynamics with uncertain simulation inputs and make use of uncertainty transfer characteristic based on polynomial chaos expansion has conducted. With a series of research, the effects of the uncertainties in calculation condition and model parameter on numerical simulation of discussed specific fluid phenomenon were clarified, and practical usages of evaluated characteristics were implemented. These series of research, a framework to account for uncertainty in computational fluid dynamics has been clarified, and implementation of the introduced framework for other fluid phenomenon is expected for a more quantitative and practical discussion of the uncertainty in fluid dynamics phenomenon.