Quantification of Modelling Uncertainties in Computational Fluid Dynamics

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Resumen Computational Fluid Dynamics (CFD) simulations and their multidisciplinary extensions (such as fluid-structure, fluid-thermal and aero-acoustics applications) form an important part of the analysis and design methods used in industry. These simulations are typically based on a unique set of input data and model variables. However, realistic operating conditions are subject to numerous uncertainties (e.g. variations in boundary and initial conditions, differences in geometry resulting from manufacturing tolerances, numerical error sources and uncertain physical models). The presence of these uncertainties is a major source of error in the design decision process and increases the risk of failure of a given component. The present research work focuses on modelling uncertainties. The fundamental assumption when estimating the parameters of a model is that the model accurately reflects the behavior of the system being studied. For typical statistical studies, the model often is simply a device for future predictions, i.e. a regression analysis, and the parameters have little or no physical or phenomenological meaning. However, for engineering and scientific analysis the model is almost always assumed to be an accurate representation of the systems behavior and the model usually incorporates the conservation equations and other sub-models (i.e., turbulence models, equations of state, ...) and is assumed to be a 'true' model. The estimation of the parameters (or properties) of the model is often done by comparing the model predictions to the data utilizing the least squares approach to minimize the differences between the predictions and the measurements. A typical example of these difficulties is provided by turbulence modelling. Several turbulence models are available in the literature, and there is a quite general agreement about the fact that no universal turbulence model exists, i.e. the performance of different turbulence models is strongly problem-dependent, both in terms of accuracy and efficiency. Moreover, a specific turbulence model uses a number of closure coefficients which are traditionally determined by calibrating the model for a dataset of relatively simple test cases. It is however well known that the model performance may strongly depend on the selected coefficients, which are often "recalibrated" (typically trying to fit some available experimental data) to improve the model response for a given set of problems. After providing an overview of modelling problems in CFD, we provide perspectives about the study of modelling uncertainties, through a Bayesian approach, i.e. based on Thomas Bayes theory of probability and statistical inference, which suggests representing uncertainty with probability. In the present case of modelling uncertainties, probability represents our confidence in some proposition, given all of the currently available information. More importantly, Bayes' theorem provides a suitable formalism to update that confidence (probability) when new information becomes available.