

# Experimental Evaluation of Ship Resistance for RANS Code Validation

G. Avanzini, L. Benedetti and R. Penna  
Italian Ship Model Basin (INSEAN), Rome, Italy

## ABSTRACT

**Experimental results for CFD codes' validation are required to be very precise and the uncertainty must be kept under a given interval with known confidence. These requirements have a strong influence on both the design and the execution phases of experiments. In this paper the detailed uncertainty analysis for resistance measurement at different Froude numbers (execution phase) and the general uncertainty analysis for longitudinal wave cuts (design phase) are presented. The classical approach for uncertainty analysis is followed. Some considerations on position-dependent measurements are also presented to evaluate errors due to the uncertainty in the probe position during field measurements.**

## INTRODUCTION

Recent advances in numerical simulation of physical phenomena have changed the role of experiments: They are no longer the only alternative to get data in such cases where a numerical solution cannot be found, rather they have become a tool to validate results obtained by state-of-the-art codes (Longo and Stern, 1995). Following the definition presented in Melnick et al. (1994), validation is a process of testing a verified computer code to establish the ability of the code to accurately model critical physics over a defined range of parameters and error bands. This is established by comparison with benchmark experimental data.

Fluid dynamics is one of the fields where this evolution is having the strongest influence. We only cite here the case of RANS codes (Reynolds Averaged Navier-Stokes, e.g., Hirsch, 1989), a very promising numerical tool for obtaining reliable solutions for flows past bodies of complex shape, including turbulence effects. In the near future RANS codes will enable researchers to get reasonable numerical estimates of all the contributions to ship resistance, without expensive and time-consuming experiments. As a matter of fact, experiments will become an ever less routine activity; nonetheless the validation procedure still needs experimental results of known accuracy, in order to make a meaningful comparison between numerical and experimental data. This procedure is of critical importance in Computational Fluid Dynamics (CFD), especially when dealing with codes that include turbulence models. The models are usually tuned with respect to experimental data obtained for extremely simple geometries, in order to keep both computational and experimental effort to an acceptable level. Unfortunately the tuning process seems to depend heavily on the actual geometry of the test case, so that the results obtained on a simple geometry correlate poorly with those that would be obtained on a realistic one (e.g., in the case of naval applications, a hull, with bulb, transom stern and appendices).

The accuracy level necessary in experimental test cases for a reliable code validation requires increasingly sophisticated equipment and, at the same time, a good knowledge of the accuracy itself, in the form of uncertainty and confidence in the measured

value, that is, the probability that the measured value falls within the estimated uncertainty. These requirements have a strong influence over the entire experimental process, from the early design stages through the debugging and execution phases of the experiments, up to the final analysis of the data (Coleman and Steele, 1989). In the last 15 years great effort has been devoted to defining standardised procedures for the evaluation of the reliability of data obtained from experiments. We only cite here as a reference one of the most recent works by Coleman (1995) together with the well-known ANSI/ASME Standard for Measurement Uncertainty (1986) and the AIAA Standard for wind tunnel testing (1995).

The application of the uncertainty analysis to real world experiments has to face many different problems. As recognised in Coleman and Steele (1989), to single out all the possible sources of bias error in an experimental measurement can be difficult, and once the error source is determined, the evaluation of the bias with the desired degree of confidence is often not a trivial task. Apparently, the evaluation of the precision index of a measurement is easier, once a sufficient number of samples is available, because it relies on well-known statistical tools. But a given precision requirement can be met only if the standard deviation is sufficiently small and the number of readings sufficiently large. Time and/or budget constraints can make it difficult (if not impossible) to make a large number of readings for the same experiment. Moreover, when a variable is to be determined as a function of several measured quantities, the sensitivity coefficient in the error propagation equation can multiply the error on some of the measured quantities by a factor greater than 1 (Coleman and Steele, 1989). The analysis of the error in the measure of time- and/or position-dependent variables is even more difficult. We will show how an error in the position of the probe of the instrument propagates into the measured quantity multiplied by a sensitivity coefficient depending on the field itself. A refined grid would allow the evaluation of these coefficients, but also this estimate is affected by an error due to the wrong position of the probe.

In the next part of the paper a brief outline of the classical approach to uncertainty analysis will be given. We refer the reader to the work of Coleman and Steele (1989) for the derivation of most of the equations reported in what follows, for the nomenclature and the terminology used, and for a bulk of precious examples that served as a guideline throughout our work. The effect of probe-positioning errors on measurements will be analysed with more detail, as it is not covered in classical textbooks on uncer-

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