A Novel Flow-chart for Model Validation: Is it Conceivable to Validate without New Measurements?

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ABSTRACT

The ASME V&V guide contains a recommendation that the validation process should comprise of the synchronous implementation of a simulation and physical tests. This has been widely-accepted to be the appropriate approach to conducting a validation process using measurements from experiments designed specifically for the purpose of supporting a model validation process. However, the advent of the digital twin has led to the option to consider other process flows for a model validation. A digital twin consists of a computational model of a system, usually generated and validated during a design process, combined with quality assurance measurements made during manufacturing, information about service conditions, health monitoring data, and measurements made during maintenance inspections. A digital twin combined with end-of-life assessments of the physical system represent a vast wealth of information and knowledge about the system's life-cycle performance. This knowledge has immense potential value in the design of successor systems, including offering the prospect of historical measurement data to support a validation process for a model of the next generation system. The impact of this potential on the process flow for validation of computational models of structural systems has been reviewed and a new flow-chart is proposed. The new flow-chart has some key novel features such as the inclusion of historical data, modelling credentials, a validation metric and a decision-maker's review. The features of the new flow-chart and implications for experimental mechanics will be discussed.

Keywords: Model validation, digital twins, experimental mechanics, historical data

INTRODUCTION

The process to be followed in the validation of computational models has been codified in AIAA [1], ASME [2] and most recently, in CEN [3] documents. There is a consensus around the meaning of validation of models, i.e. 'the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model'. There also seems to be a majority view in the literature that this implies designing and conducting experiments for the purpose of providing measurement data to support a validation process. Indeed, that was an explicit recommendation from a recent round-robin, or inter-laboratory exercise, to explore the efficacy of the validation process described in the CEN Workshop Agreement [4]. However, according to Forrester [reported by Barlas and Carpenter [5]], 'operators' see validity as 'relative usefulness' as opposed to 'observers' and the literature which consider it as a 'formal logic concept rather than a pragmatic issue', which suggests that there might be some differences between the reported approaches to validation of computational models and their predictions and the processes undertaken in industry. These differences have been explored in the EU research project called MOTIVATE which is an acronym meaning 'Matrix Optimization for Testing by Interaction of Virtual and Test Environments'. The Clean Sky 2 project is being conducted by a consortium consisting of the University of Liverpool, EMPA, Dantec Dynamics GmbH and the Athena Research Centre with Airbus as the Topic Manager. For a complex engineering system, such as a passenger aircraft, the cost of conducting experiments to generate measurement data for a validation process are very high, perhaps prohibitively so in a highly competitive marketplace. However, it is clear that validation is required to ensure that aircraft designs are safe and reliable, which implies that the need to conduct extensive experiments expressly designed and executed for the validation of computational models could inhibit or stifle innovation in design and in model development. Hence, the MOTIVATE project has begun to examine the usefulness and approaches that might be taken to utilizing historical measurement data to support validation processes. This leads quite quickly to also considering the use of historical simulation data when it is desired to extend scope and validity of any existing computational model. Figure 1 shows the result of a series of brain-storming sessions held by the MOTIVATE consortium with input from NPL, who were partners in an early project that led to the development of the CEN Workshop Agreement [3].

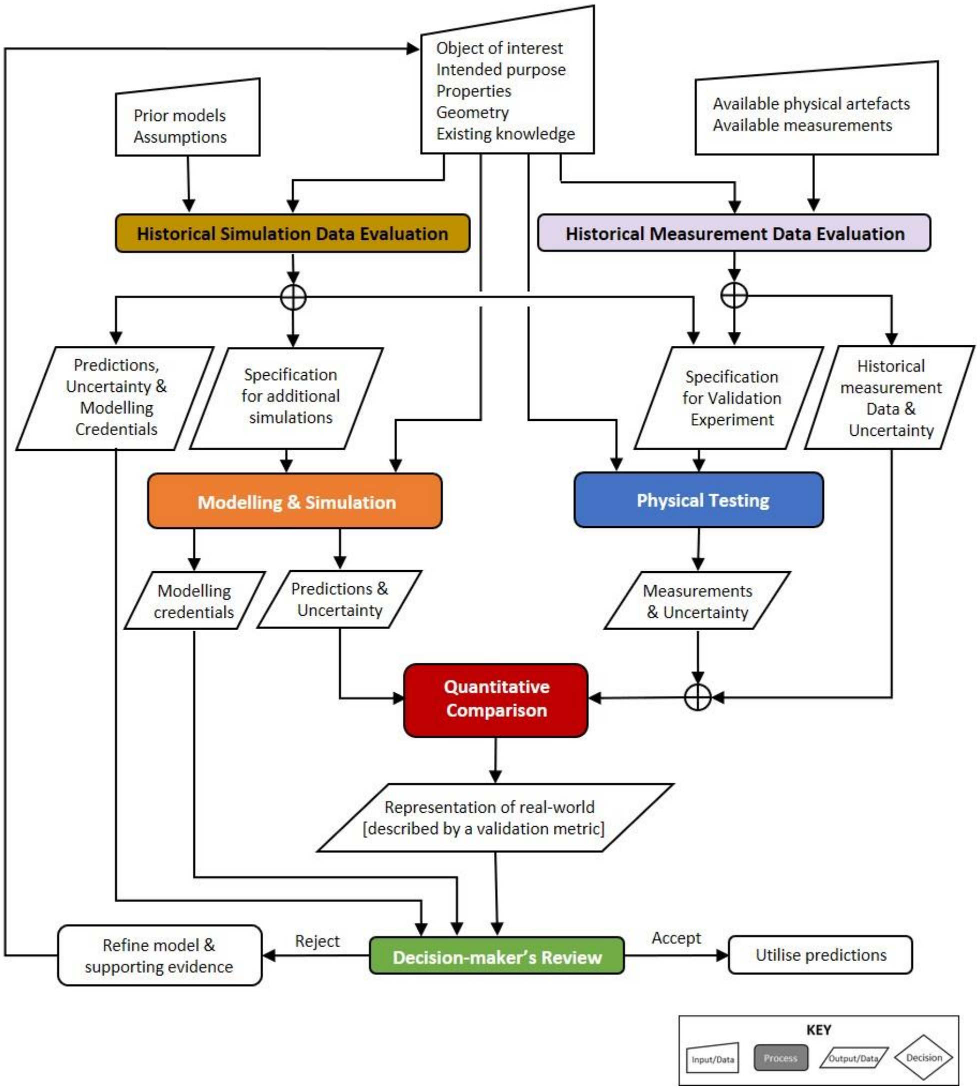

Figure 1: Proposed new flowchart for the process of validating simulations that allows the use of historical data and which is broadly based on the corresponding ASME flowchart. The processes within the color-shaded boxes are illustrated in figures 2 to 4.

METHODOLOGY

The flowchart in figure 1 and its supporting sub-processes shown in figures 2 to 4 are put forward as a proposal for a rigorous validation process that satisfies the definition of a validation process for computational mechanics models, as specified by AIAA [1], ASME [2] and CEN [3], but which allows the use of historical data as is perhaps not uncommon in engineering practice. At this stage, they are presented in a spirit of consultation and discussion within the community and feedback on them is welcomed by the partners in the MOTIVATE project.

The main flowchart in figure 1 follows the structure of the classical flowchart found in the ASME guide [2] with the starting point being the identification of the 'reality of interest', as it is termed in the ASME guide, and defined in figure 1 as the object of interest, its intended purpose, properties and geometry. This information together with existing knowledge are inputs to the validation process which proceeds along two streams in figure 1, as in the ASME guide, with modelling and simulation on the left and with experimentation or physical testing on the right. However, consideration of historical data has been introduced as a first step in each of these streams and these sub-processes are shown in figure 2.

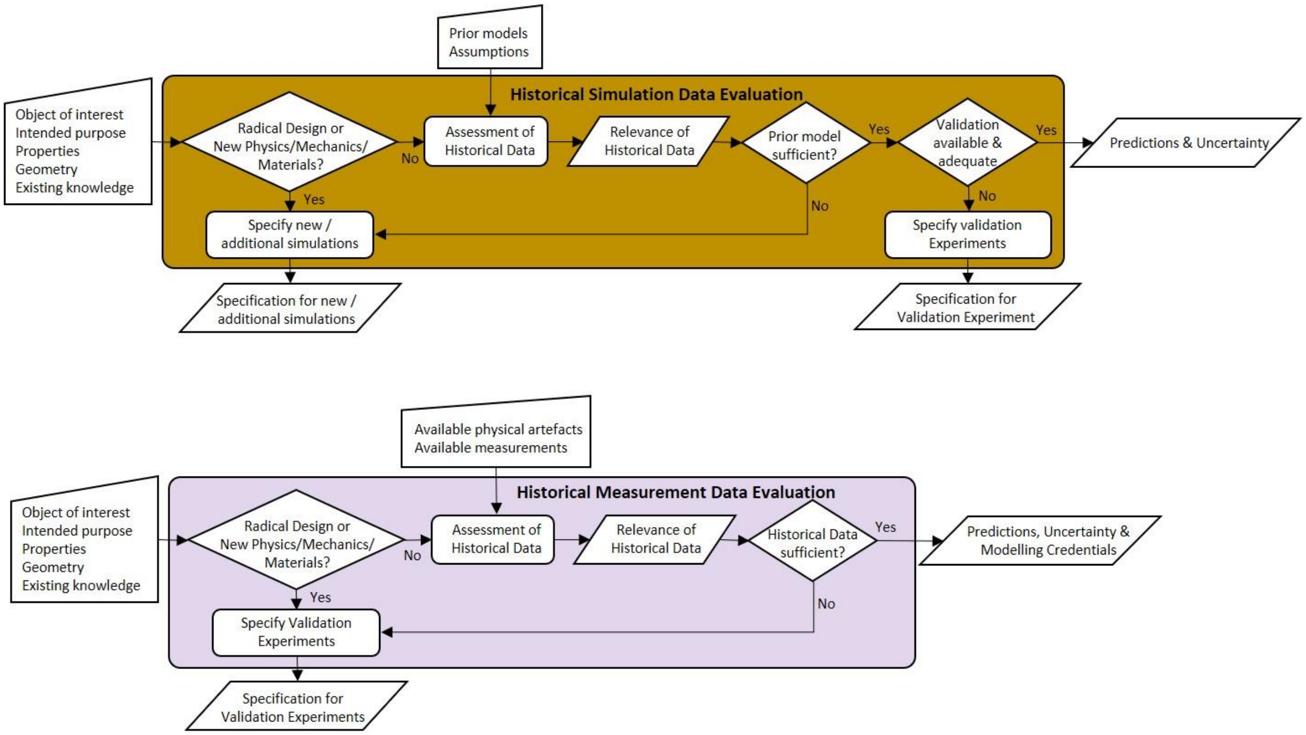

Figure 2: Flowcharts for the processes of Historical Simulation Data Evaluation (top) and Historical Measurement Data Evaluation (bottom) shown in the main Simulation Validation flowchart in Figure 1.

In the interests of simplicity, every effort has been made to align the process of evaluating historical simulation and measurement data. The key step is to establish whether or not the model to be validated pertains to a radical new design, or involves new physics, mechanics or materials relative to the historical data; if the answer is positive then historical data is not useful and it is necessary to specify new validation experiments or additional simulations. However, if the outcome is negative, then the historical data is potentially useful, and it is necessary to assess its relevance and sufficiency for the validation process. If the historical data is both relevant and sufficient then it can be used in the validation process without further experiments or simulation; but if this is not the case, then it will be necessary to specify new validation experiments or additional simulations. The flowchart is lop-sided following a successful evaluation of historical data because historical simulation data can be used directly in a decision-maker's review of a model, whereas historical measurement data would be used in a quantitative comparison with predictions from a model.

The sub-process of physical testing shown in figure 3 is essentially the same as in the ASME flowchart although the inputs and outputs have been explicitly identified. However, the sub-process of modelling and simulation is somewhat different because it divides model building into two steps: speculation and articulation, following the terminology used by Hacking [6] and Kuhn [7], because this allows model credentials derived from the theoretical ancestry of the model and the modelling praxis to be captured and to form part of the evidence used by decision-makers in assessing the usefulness of a model [8].

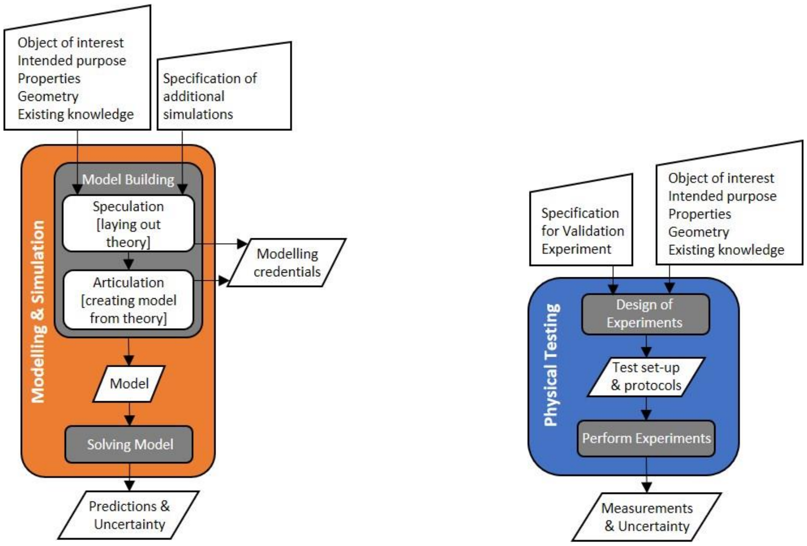

Figure 3: Flowcharts for the processes of Modelling Simulation (left) and Physical Testing (right) shown in the main Simulation Validation flowchart in Figure 1.

The quantitative comparison of measurements and simulations is shown in the flowchart on the left in figure 4 and follows the process described in the CEN Workshop Agreement [3] which recommends the use of data or strain decomposition to reduce the fields or matrices of measurements and predictions to feature vectors that can be readily compared using statistical methods, such as proposed by Sebastian et al [9]. These approaches result in a go/no-go outcome for the acceptability of the predictions based on assessing their similarity to the measurements against the uncertainty in the measurements. More recently, Dvurecenska et al [10] have demonstrated that feature vectors representing measured and predicted strain fields can be used in a relative metric to describe the extent to which the predictions represent the real-world.

The final process in the main flowchart in figure 1 is a decision-maker’s review for which the details are shown in the sub-process flowchart on the right in figure 4. This process goes beyond the simple question posed in the ASME flowchart: ‘Acceptable Agreement?’. Instead, the review process used in the nuclear industry for the review of simulations [11] is incorporated into the flowchart. This consists of deciding what level of trustworthiness is required for the specified purpose, then assessing the trustworthiness of the predictions and only after these two steps is a decision made about the acceptability of the model.

DISCUSSION AND CONCLUSION

The flowchart in figure 1 and the sub-processes described in the remaining figures represent a significant departure from the classical flowchart provided in the ASME V&V guide [2] that has been used for many years. It differs in a number of ways including allowing the use of historical data, introducing the concept of modelling credentials, proposing the use of a validation metric when handling fields or maps of data and by providing a process for the decision-maker’s review. These changes are intended to enhance and improve the validation process and not intended to contradict the current guidelines but rather to supplement them. A key motivation has been to recognize that the implementation of the formal logic of a rigorous validation process is not always viable in engineering industry and, hence, to provide mechanisms that are well-grounded in the philosophy of science and that also are practical. At the time of writing, the MOTIVATE project is conducting a trial using the proposed flowchart to validate a model of an aircraft fuselage panel before commencing a larger trial using measurement and simulations of a full-scale aircraft cockpit. In the meantime, feedback from the engineering community on the proposed flowchart is welcomed by the MOTIVATE project partners, via the project coordinator, Eann Patterson (eann.patterson@liverpool.ac.uk)

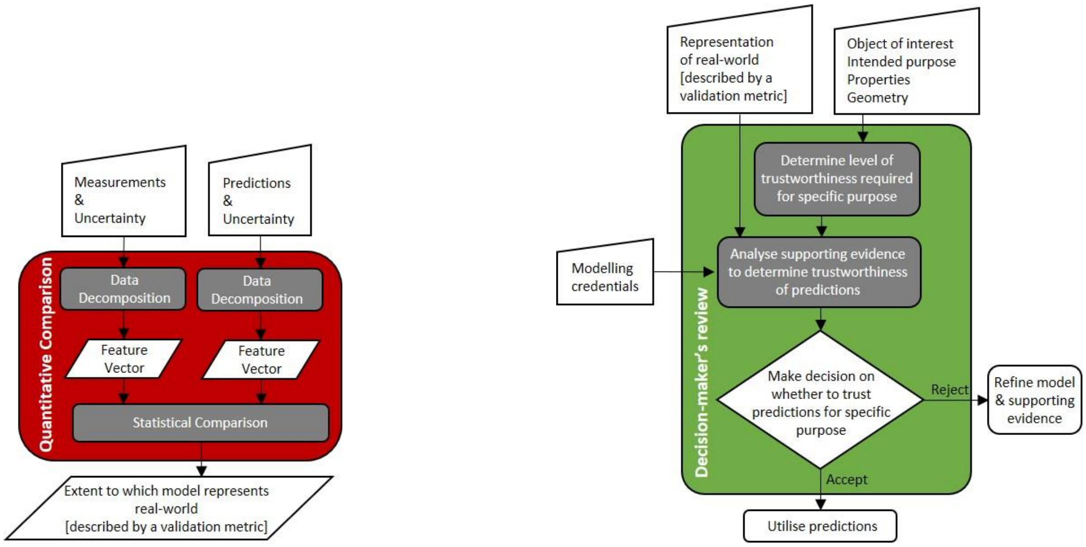

Figure 4: Flowcharts for the processes of Quantitative Comparison (left) and Decision-maker's Review (right) shown in the main Simulation Validation flowchart in Figure 1.

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