ASME V&V 10-2006

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Guide for Verification and Validation in Computational Solid Mechanics

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This Guide will be revised when the Society approves the issuance of a new edition. There will be no addenda issued to ASME V&V 10-2006.

ASME issues written replies to inquiries concerning interpretations of technical aspects of this document. Periodically certain actions of the ASME V&V Committees will be published as cases. Cases and interpretations are published on the ASME Web site under the Committee Pages at http://cstools.asme.org as they are issued.

The American Society of Mechanical Engineers
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FOREWORD

Since the mid-1960s, computer simulations have come to dominate engineering mechanics analysis for all but the simplest problems. With today's increasing reliance on complicated simulations using computers, it is necessary to use a systematic program of verification and validation (V&V) to ensure the accuracy of these simulations. This document is intended to describe such a program.

The concept of systematic V&V is not a new one. The software development community has long recognized the need for a quality assurance program for scientific and engineering software. The Institute of Electrical and Electronic Engineers, along with other organizations, has adopted guidelines and standards for software quality assurance (SQA) appropriate for developers. SQA guidelines, while necessary, are not sufficient to cover the nuances of computational physics and engineering or the vast array of problems to which end-users apply the codes. To fill this gap, the concept of application-specific V&V was developed.

Application-specific V&V has been the focus of attention for several groups in scientific and engineering communities since the mid-1990s. The Department of Defense's Defense Modeling and Simulation Office (DMSO) produced recommended practices suitable for large-scale simulations. However, the DMSO guidelines generally do not focus on the details of first-principles–based computational physics and engineering directly. For the area of computational fluid dynamics (CFD), the American Institute of Aeronautics and Astronautics (AIAA) produced the first V&V guidelines for detailed, first-principle analyses.

Recognizing the need for a similar set of guidelines for computational solid mechanics (CSM), members of the CSM community formed a committee under the auspices of the United States Association for Computational Mechanics in 1999. The American Society of Mechanical Engineers (ASME) Board on Performance Test Codes (PTC) granted the committee official status in 2001 and designated it as the PTC 60 Committee on Verification and Validation in Computational Solid Mechanics. The PTC 60 committee undertook the task of writing these guidelines. Its membership consists of solid mechanics analysts, experimenters, code developers, and managers from industry, government, and academia. Industrial representation includes the aerospace/defense, commercial aviation, automotive, bioengineering, and software development industries. The Department of Defense, the Department of Energy, and the Federal Aviation Administration represent the government.

Early discussions within PTC 60 revealed an immediate need for a common language and process definition for V&V appropriate for CSM analysts, as well as their managers and customers. This document describes the semantics of V&V and defines the process of performing V&V in a manner that facilitates communication and understanding among the various performers and stakeholders. Because the terms and concepts of V&V are numerous and complex, it was decided to publish this overview document first, to be followed in the future by detailed treatments of how to perform V&V for specific applications.

Several experts in the field of CSM who were not part of PTC 60 reviewed a draft of this document and offered many helpful suggestions. The final version of this document was approved by PTC 60 on May 11, 2006 and was approved and adopted by the American National Standards Institute on November 3, 2006.

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Subject:	Cite the applicable paragraph number(s) and the topic of the inquiry.
Edition:	Cite the applicable edition of the Guide for which the interpretation is being requested.
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PREFACE

This document provides general guidance for implementing verification and validation (V&V) of computational models for complex systems in solid mechanics. The guidance is based on the following key principles:

(a) Verification (addressing programming errors and estimating numerical errors) must precede validation (assessing a model's predictive capability by comparing calculations with experiments).

(b) The need for validation experiments and the associated accuracy requirements for computational model predictions are based on the intended use of the model and should be established as part of V&V activities.

(c) Validation of a complex system should be pursued in a hierarchical fashion from the component level to the system level.

(d) Validation is specific to a particular computational model for a particular intended use.

(e) Simulation results and experimental data must have an assessment of uncertainty to be meaningful.

Although the state of the art of V&V does not yet lend itself to writing a step-by-step performance code/standard, this guide provides the computational solid mechanics (CSM) community with a common language and conceptual framework to enable managers and practitioners of V&V to better assess and enhance the credibility of CSM models. Implementation of a range of V&V activities is discussed, including model development for complex systems, verification of numerical solutions to governing equations, attributes of validation experiments, accuracy requirements, and quantification of uncertainties. Remaining issues for further development of a V&V protocol are identified.

GUIDE FOR VERIFICATION AND VALIDATION IN COMPUTATIONAL SOLID MECHANICS

1 EXECUTIVE SUMMARY

Program managers need assurance that computational models of engineered systems are sufficiently accurate to support programmatic decisions. This document provides the technical community — engineers, scientists, and program managers — with guidelines for assessing the credibility of computational solid mechanics (CSM) models.

Verification and validation (V&V) are the processes by which evidence is generated, and credibility is thereby established, that computer models have adequate accuracy and level of detail for their intended use. Definitions of V&V differ among segments of the practicing community. The PTC 60 committee has chosen definitions consistent with those published by the Defense Modeling and Simulation Office of the Department of Defense (DoD) [1] and by the American Institute of Aeronautics and Astronautics (AIAA) in their 1998 Guide for the Verification and Validation of Computational Fluid Dynamics [2], which the present American Society of Mechanical Engineers (ASME) document builds upon. Verification assesses the numerical accuracy of a computational model, irrespective of the physics being modeled. Both code verification (addressing errors in the software) and calculation verification (estimating numerical errors due to under-resolved discrete representations of the mathematical model) are addressed. Validation assesses the degree to which the computational model is an accurate representation of the physics being modeled. It is based on comparisons between numerical simulations and relevant experimental data. Validation must assess the predictive capability of the model in the physical realm of interest, and it must address uncertainties that arise from both experimental and computational procedures.

Although the state of the art of V&V does not yet lend itself to writing a step-by-step performance code/standard, the guidance provided here will enable managers and practitioners of V&V to better assess and enhance the credibility of CSM models. The PTC 60 Committee recognizes that program needs and resources vary and that the application of the guidance provided in this document to specific cases must accommodate specific budget and risk considerations. The scope of this document is to explain the principles of V&V so that practitioners can better appreciate and understand how decisions made during V&V can impact their ability to assess and enhance the credibility of CSM models.

As suggested by Fig. 1, the V&V processes begin with a statement of the intended use of the model so that the relevant physics are included in both the model and the experiments performed to validate the model. Modeling activities and experimental activities are guided by the response features of interest and the accuracy requirements for the intended use. Experimental outcomes for component-level, subsystem-level, or system-level tests should, whenever possible, be provided to modelers only after the numerical simulations for them have been performed with a verified model. For a particular application, the V&V processes end with acceptable agreement between model predictions and experimental outcomes after accounting for uncertainties in both, allowing application of the model for the intended use. If the agreement between model and experiment is not acceptable, the processes of V&V are repeated by updating the model and performing additional experiments.

Finally, the importance of documentation in all of the V&V activities should be emphasized. In addition to preserving the compiled evidence of V&V, documentation records the justifications for important decisions, such as selecting primary response features and setting accuracy requirements. Documentation thereby supports the primary objective of V&V: to build confidence in the predictive capability of computational models. Documentation also provides a historical record of the V&V processes, provides traceability during an engineering audit, and captures experience useful in mentoring others.

2 INTRODUCTION

CSM is playing an increasingly important role in the design and performance assessment of engineered systems. Automobiles, aircraft, and weapon systems are examples of engineered systems that have become more and more reliant on computational models and simulation results to predict their performance, safety, and reliability. Although important decisions are made based on CSM, the credibility (or trustworthiness) of these models and simulation results is oftentimes not questioned by the general public, the technologists who design and build the systems, or the decision makers