ASME V&V 20-2009

Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer

AN AMERICAN NATIONAL STANDARD



The American Society of Mechanical Engineers

ASME SETTING THE STANDARD

Copyright © 2009 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.



ASME V&V 20-2009

Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer

AN AMERICAN NATIONAL STANDARD



The American Society of Mechanical Engineers

ASME SETTING THE STANDARD

Copyright © 2009 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.



Date of Issuance: November 30, 2009

This Standard will be revised when the Society approves the issuance of a new edition. There will be no addenda issued to this edition.

ASME issues written replies to inquiries concerning interpretations of technical aspects of this Standard. Periodically certain actions of the ASME V&V 20 Committee may 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.

ASME is the registered trademark of The American Society of Mechanical Engineers.

This code or standard was developed under procedures accredited as meeting the criteria for American National Standards. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment that provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not approve, rate, or endorse any item, construction, proprietary device, or activity.

ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable letters patent, nor assumes any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representative(s) or person(s) affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations of this document issued in accordance with the established ASME procedures and policies, which precludes the issuance of interpretations by individuals.

No part of this document may be reproduced in any form,
in an electronic retrieval system or otherwise,
without the prior written permission of the publisher.

The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

Copyright © 2009 by
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
All rights reserved
Printed in U.S.A.

Copyright © 2009 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.



CONTENTS

Foreword vi
Committee Roster viii
Correspondence With the V&V 20 Committee ix

Section 1 Introduction to Validation Methodology 1
1-1 General 1
1-2 Objective and Scope 1
1-3 Errors and Uncertainties 1
1-4 Example for Validation Nomenclature and Approach 2
1-5 Validation Approach 3
1-6 Overview of Subsequent Sections 5
1-7 References 5

Section 2 Code Verification and Solution Verification 7
2-1 General 7
2-2 Introduction 7
2-3 Code Verification 7
2-4 Solution Verification 11
2-5 Special Considerations 16
2-6 Final Comment 17
2-7 References 17

Section 3 Effect of Input Parameter Uncertainty on Simulation Uncertainty 19
3-1 Introduction 19
3-2 Sensitivity Coefficient (Local) Method for Parameter Uncertainty Propagation 19
3-3 Sampling (Global) Methods for Parameter Uncertainty Propagation 23
3-4 Importance Factors 25
3-5 Special Considerations 25
3-6 Final Comment on Parameter Uncertainty 26
3-7 References 26

Section 4 Uncertainty of an Experimental Result 27
4-1 Overview 27
4-2 Experimental Uncertainty Analysis 27
4-3 Uncertainty of Validation Experiment 28
4-4 Summary 28
4-5 References 28

Section 5 Evaluation of Validation Uncertainty 30
5-1 Overview 30
5-2 Estimating u_{val} When the Experimental Value, D, of the Validation Variable is Directly Measured (Case 1). 30
5-3 Estimating u_{val} When the Experimental Value, D, of the Validation Variable is Determined From a Data Reduction Equation (Cases 2 and 3) 31
5-4 Estimating u_{val} When the Experimental Value, D, of the Validation Variable is Determined From a Data Reduction Equation That Itself Is a Model (Case 4). 36
5-5 Assumptions and Issues 37
5-6 References 39

Section 6 Interpretation of Validation Results 40
6-1 Introduction 40
6-2 Interpretation of Validation Results Using E and u_{val} With No Assumptions Made About Error Distributions. 40

Copyright © 2009 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.

6-3 Interpretation of Validation Results Using E and u_{val} With Assumptions Made About Error Distributions . . . 40
6-4 References . . . 41

Section 7 Examples . . . 42
7-1 Overview . . . 42
7-2 Code Verification Example . . . 42
7-3 Validation Example . . . 48
7-4 References . . . 65

Figures

1-4-1 Schematic of Finned-Tube Assembly for Heat Transfer Example . . . 2
1-5-1 Schematic Showing Nomenclature for Validation Approach . . . 3
1-5-2 Overview of the Validation Process With Sources of Error in Ovals . . . 4
2-4-1 Sample Uncertainty Analysis: Explosive Detonation in a Fluid Filled Box . . . 15
3-2-1 Relative Error in Finite Difference Computation of $k\partial T/\partial k$ Using a Backwards Difference . . . 21
3-2-2 Estimated Uncertainty in Model Temperature Due to Uncertainty in q, k, and ρc_p . . . 22
3-3-1 Representative Probability Distribution Function for Thermal Conductivity . . . 23
3-3-2 Standard Deviation in Temperature at $z/L = 0$ and 1 for Constant Heat Flux Example Using 10 LHS Runs and Mean Value Method (With $u_X/X = 0.05$) . . . 25
5-1-1 Schematic for Combustion Gas Flow Through a Duct With Wall Heat Flux Being the Validation Variable (Case 4) . . . 30
5-2-1 Sensitivity Coefficient Propagation Approach for Estimating u_{val} When the Validation Variable (T_o) Is Directly Measured (Case 1) . . . 32
5-2-2 Monte Carlo Approach for Estimating u_{val} When the Validation Variable (T_o) Is Directly Measured (Case 1) . . . 32
5-3-1 Sensitivity Coefficient Propagation Approach for Estimating u_{val} When the Validation Variable Is Defined by a Data Reduction Equation That Combines Variables Measured in the Experiment (Case 2) . . . 34
5-3-2 Monte Carlo Approach for Estimating u_{val} When the Validation Variable Is Defined by a Data Reduction Equation That Combines Variables Measured in the Experiment (Case 2) . . . 34
5-3-3 Sensitivity Coefficient Propagation Approach for Estimating u_{val} When the Validation Variable Is Defined by a Data Reduction Equation That Combines Variables Measured in the Experiment and Two Measured Variables Share an Identical Error Source (Case 3) . . . 35
5-3-4 Monte Carlo Propagation Approach for Estimating u_{val} When the Validation Variable Is Defined by a Data Reduction Equation That Combines Variables Measured in the Experiment and Two Measured Variables Share an Identical Error Source (Case 3) . . . 36
5-4-1 Sensitivity Coefficient Propagation Approach for Estimating u_{val} When the Validation Variable Is Defined by a Data Reduction Equation That Itself Is a Model (Case 4) . . . 37
5-4-2 Monte Carlo Propagation Approach for Estimating u_{val} When the Validation Variable Is Defined by a Data Reduction Equation That Itself Is a Model (Case 4) . . . 38
7-2-1 Problem Domain With (x, y) Coordinates Shown for Domain Corners . . . 42
7-2-2 Finite Element Meshes Used in the Code Verification Refinement Study . . . 44
7-2-3 Error as a Function of Characteristic Mesh Size . . . 47
7-3-1 Schematic of Fin-Tube Heat Exchanger Assembly . . . 48
7-3-2 Experimental Total Heat Transfer Rate and Its Standard Uncertainty, u_D . . . 51
7-3-3 Heat Transfer Model for the Fin-Tube Assembly . . . 52
7-3-4 Mesh Refinement Study for Solution Verification . . . 55
7-3-5 Simulation Values of Total Heat Transfer Rate and Its Uncertainty, u_{input} . . . 57
7-3-6 LHS Samples of Simulated and Experimental Values of Total Heat Transfer Rate . . . 60
7-3-7 Interval for $\boldsymbol{\delta}_{model}$ ($E \pm 2u_{val}$) Assuming a Gaussian Distribution for the Errors and 95% Probability . . . 61
7-3-8 Interval for $\boldsymbol{\delta}_{model}$ ($E \pm 2u_{val}$) Assuming a Gaussian Distribution for the Errors and 95% Probability for the Model With Contact Conductance at the Fin/Tube Interface . . . 65

Copyright © 2009 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.

Tables

2-4-1 Sample Uncertainty Analysis: Backward Facing Step . . . 15
2-4-2 Sample Uncertainty Analysis: Explosive Detonation . . . 16
3-3-1 Matrix Representation of Number of LHS Samples (n_{LHS}) and Number of Parameters (n_p) . . . 24
3-3-2 LHS Samples for the Three Parameters q, k, and C . . . 24
7-2-1 Parameter Values Used for the Code Verification Example . . . 45
7-2-2 Code Verification Results . . . 45
7-2-3 Error (E_h) in the Code Simulation During Mesh Refinement . . . 46
7-2-4 Observed Order of Convergence (p^{obs}) From Mesh Refinement . . . 47
7-3-1 Details of the Fin-Tube Assembly and Flow Conditions . . . 49
7-3-2 Measured Flow Conditions and Calculated Total Heat Transfer Rate . . . 50
7-3-3 Estimates of the Experimental Measurement Standard Uncertainties . . . 50
7-3-4 Sensitivity Coefficients for Average Conditions . . . 50
7-3-5 Experimental Values of Total Heat Transfer Rate and Its Standard Uncertainties . . . 51
7-3-6 Simulation Model Input Parameters and Standard Uncertainties . . . 53
7-3-7 Simulation Values of Total Heat Transfer Rate . . . 54
7-3-8 Solution Verification Results for Total Heat Transfer Rate . . . 54
7-3-9 Measures of the Numerical Error and Numerical Uncertainty for Total Heat Transfer Rate . . . 55
7-3-10 Partial Derivatives of the Total Heat Transfer Rate for the Simulation Model With Respect to Uncertain Model Inputs for the Average of Measured Experimental Conditions and Standard Uncertainty for the Inputs . . . 56
7-3-11 Simulation Values of Total Heat Transfer Rate and Its Standard Uncertainty From Input Parameter Uncertainty . . . 56
7-3-12 Parameters Included in Evaluating u_{val}, Parameter Standard Uncertainty Estimates, and Parameter Sensitivity Coefficients . . . 58
7-3-13 Experimental and Simulation Values of Total Heat Transfer Rate and Associated Standard Uncertainties . . . 58
7-3-14 Parameter Standard Uncertainty and Example Latin Hypercube Samples . . . 59
7-3-15 LHS Samples for the Simulated and Experimental Values of the Total Heat Transfer Rate . . . 60
7-3-16 Comparison of Nominal Values and Standard Uncertainties Computed With the Propagation and LHS Approaches . . . 60
7-3-17 Simulation Values of the Total Heat Transfer Rate for the Model With Contact Conductance . . . 62
7-3-18 Simulation Values of the Total Heat Transfer Rate and the Standard Uncertainty for the Model With Contact Conductance . . . 63
7-3-19 Solution Verification Results for Total Heat Transfer Rate for the Model With Contact Conductance . . . 63
7-3-20 Measures of the Numerical Error and Numerical Uncertainty for Total Heat Transfer Rate for the Model With Contact Conductance . . . 63
7-3-21 Partial Derivatives of the Total Heat Transfer Rate for the Simulation Model With Respect to Uncertainty Model Inputs for Model With Contact Conductance for the Average Measured Conditions . . . 64
7-3-22 Parameters Included in Evaluating u_{val}, Parameter Standard Uncertainty Estimates, and Parameter Sensitivity Coefficients for the Model With Contact Conductance . . . 64
7-3-23 Experimental and Simulation Values of Total Heat Transfer Rate and Associated Uncertainties . . . 65

Mandatory Appendices

I Detailed Development of Simulation Equations for Example Problem . . . 67
II Nomenclature . . . 70

Nonmandatory Appendices

A Method of Manufactured Solutions for the Sample Problem . . . 72
B Importance Factors . . . 78
C Additional Topics . . . 82

Copyright © 2009 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.

FOREWORD

This Standard addresses verification and validation (V&V) in computational fluid dynamics (CFD) and computational heat transfer (CHT). The concern of V&V is to assess the accuracy of a computational simulation. The V&V procedures presented in this Standard can be applied to engineering and scientific modeling problems ranging in complexity from simple lumped masses, to 1-D steady laminar flows, to 3-D unsteady turbulent chemically reacting flows. In V&V, the ultimate goal of engineering and scientific interest is validation, which is defined as 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. However, validation must be preceded by code verification and solution verification. Code verification establishes that the code accurately solves the mathematical model incorporated in the code, i.e. that the code is free of mistakes for the simulations of interest. Solution verification estimates the numerical accuracy of a particular calculation.

The estimation of a range within which the simulation modeling error lies is a primary objective of the validation process and is accomplished by comparing a simulation result (solution) with an appropriate experimental result (data) for specified validation variables at a specified set of conditions. *There can be no validation without experimental data with which to compare the result of the simulation.*[*] Usually a validation effort will cover a range of conditions within a domain of interest.

Both the American Institute of Aeronautics and Astronautics (AIAA) and the American Society of Mechanical Engineers (ASME) have published V&V Guides that present the philosophy and procedures for establishing a comprehensive validation program, but both use definitions of error and uncertainty that are not demonstrated within the guides to provide quantitative evaluations of the comparison of the validation variables predicted by simulation and determined by experiment. ASME V&V 10-2006, for instance, defines error as "a recognizable deficiency in any phase or activity of modeling or experimentation that is not due to lack of knowledge" and defines uncertainty as "a potential deficiency in any phase or activity of the modeling, computation, or experimentation process that is due to inherent variability or lack of knowledge."

In contrast, this Standard presents a V&V approach that is based on the concepts and definitions of error and uncertainty that have been internationally codified by the experimental community over several decades. In 1993, the Guide to the Expression of Uncertainty in Measurement was published by the International Organization for Standardization (ISO) in its name and those of six other international organizations.[†] According to the Foreword in the ISO Guide, "In 1977, recognizing the lack of international consensus on the expression of uncertainty in measurement, the world's highest authority in metrology, the Comite International des Poids et Mesures (CIPM), requested the Bureau International des Poids et Mesures (BIPM) to address the problem in conjunction with the national standards laboratories and to make a recommendation." After several years of effort, this led to the assignment of responsibility to the ISO Technical Advisory Group on Metrology, Working Group 3, to develop a guidance document. This ultimately culminated in the publication of the ISO Guide, which has been accepted as the de facto international standard for the expression of uncertainty in measurement.

The V&V approach presented in this Standard applies these concepts to the errors and uncertainties in the experimental result and also to the errors and uncertainties in the result from the simulation. Thus, the uncertainties in the experimental value and in the simulation value are treated using the same process. Using the approach of the ISO Guide, for each error source (other than the simulation modeling error) a standard uncertainty, u, is estimated such that u is the standard deviation of the parent population of possible errors from which the current error is a single realization. This allows estimation of a range within which the simulation modeling error lies.

The objective of this Standard is the specification of a verification and validation approach that quantifies the degree of accuracy inferred from the comparison of solution and data for a specified variable at a specified validation point. The scope of this Standard is the quantification of the degree of accuracy for cases in which the conditions of the actual experiment are simulated. Consideration of the accuracy of simulation results at points within a domain other than the validation points (e.g., interpolation/extrapolation in a domain of validation) is a matter of engineering judgment specific to each family of problems and is beyond the scope of this Standard.

---

[*]This is implicit in the phrase "real world" used in the definition of validation.

[†]Bureau International des Poids et Mesures (BIPM), International Electrotechnical Commission (IEC), International Federation of Clinical Chemistry (IFCC), International Union of Pure and Applied Chemistry (IUPAC), International Union of Pure and Applied Physics (IUPAP), and International Organization of Legal Metrology (OIML)

Copyright © 2009 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.

ASME PTC 19.1-2005 "Test Uncertainty" is considered a companion document to this Standard, and it is assumed the user has both so many of the details of estimating the uncertainty in an experimental result are not repeated herein. ASME PTC 19.1-2005 illustrates the application of the ISO Guide methodology in straightforward and also in complex experiments.

Ideally, as a V&V program is initiated, those responsible for the simulations and those responsible for the experiments should be involved cooperatively in designing the V&V effort. The validation variables should be chosen and defined with care. Each measured variable has an inherent temporal and spatial resolution, and the experimental result that is determined from these measured variables should be compared with a predicted result that possesses the same spatial and temporal resolution. If this is not done, such conceptual errors must be identified and corrected or estimated in the initial stages of a V&V effort, or substantial resources can be wasted and the entire effort may be compromised.

Finally, as an aid to the reader of this Standard, the following guide to the topics and discussions of each section are presented. It is recommended that the reader proceed through the Standard beginning in Section 1 and successively read each subsequent section. The presentation in this Standard follows a procedure starting with verification (code and solution), proceeding to parameter uncertainty assessment, experimental uncertainty assessment, simulation validation, and concluding with a comprehensive example problem. As stated, this Standard follows an overall procedure; however, each section of this Standard may also be viewed as a standalone presentation on each of the relevant topics. The intent of this document is validation in which uncertainty is determined for both the experimental data and the simulation of the experiment. However, the material in Sections 2, 3, and 4 can be studied independently of the remainder of the document as they are important in their own right. A reader's guide follows:

Section 1 presents an introduction to the concepts of verification and validation, the definitions of error and uncertainty, and the introduction of the overall validation methodology and approach as defined in this Standard. The key concepts of this Section are the validation comparison error and the validation standard uncertainty. It is shown that validation standard uncertainty is a function of three standard uncertainties associated with errors due to numerical solution of the equations, due to simulation inputs, and due to experimental data.

Section 2 presents two key topics:

(a) the details of a method for code verification based on the technique of the method of manufactured solutions

(b) the details of a method for solution verification based on the technique of the Grid Convergence Index (an extension of Richardson Extrapolation).

The outcome of Section 2 is a method for estimating the standard uncertainty associated with numerical errors.

Section 3 presents two different approaches for estimating the standard uncertainty associated with errors in simulation input parameters. One approach evaluates response of the simulation or system in a local neighborhood of the input vector, while the other approach evaluates response in a larger global neighborhood. The first approach is commonly referred to, for example, as the sensitivity coefficient method, and the second approach is generally referred to as the sampling or Monte Carlo method.

Section 4 presents a brief overview of the method presented in the ASME PTC 19.1-2005 Test Uncertainty standard for estimating uncertainty in an experimental result. At the conclusion of this Section, the reader will have methods for estimating the key uncertainties required to complete a validation assessment.

Section 5 presents two approaches for estimating the validation standard uncertainty given the estimates of uncertainty associated with numerical, input, and experimental data errors as developed in the three previous sections. At the conclusion of this Section, the reader will have the necessary tools to estimate validation standard uncertainty and the error associated with the mathematical model.

Section 6 presents a discussion of the interpretation of the key validation metrics of validation comparison error and validation uncertainty. It is shown that the validation comparison error is an estimate of the mathematical model error and that the validation uncertainty is the standard uncertainty of the estimate of the model error.

Section 7 summarizes the methods presented in the previous sections by implementing them in a comprehensive example problem working through each element of the overall procedure and results in a complete validation assessment of a candidate mathematical model.

Finally, several appendices are included in this Standard. Some are considered as part of the Standard and are identified as mandatory appendices. Other included appendices are considered as nonmandatory or supplementary and are identified as such.

ASME V&V 20-2009 was approved by the V&V 20 (previously PTC 61) Committee on January 9, 2009 and approved by the American National Standards Institute (ANSI) on June 3, 2009.

Copyright © 2009 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.

ASME PTC COMMITTEE
Performance Test Codes

(The following is the roster of the Committee at the time of approval of this Standard.)

STANDARDS COMMITTEE OFFICERS

M. P. McHale, *Chair*
J. R. Friedman, *Vice Chair*
J. H. Karian, *Secretary*

STANDARDS COMMITTEE PERSONNEL

P. G. Albert
R. P. Allen
J. M. Burns
W. C. Campbell
M. J. Dooley
J. R. Friedman
G. J. Gerber
P. M. Gerhart
T. C. Heil
R. E. Henry
J. H. Karian
D. R. Keyser
T. K. Kirkpatrick
S. J. Korellis
M. P. McHale
P. M. McHale
J. W. Milton
S. P. Nuspl
R. R. Priestley
J. A. Rabensteine
J. A. Silvaggio, Jr.
W. G. Steele, Jr.
J. C. Westcott
W. C. Wood

HONORARY MEMBERS

R. L. Bannister
W. O. Hays
R. Jorgensen
F. H. Light
G. H. Mittendorf, Jr.
J. W. Siegmund
R. E. Sommerlad

V&V 20 COMMITTEE — VERIFICATION AND VALIDATION IN COMPUTATIONAL FLUID DYNAMICS AND HEAT TRANSFER

H. W. Coleman, *Chair*, University of Alabama, Huntsville
C. J. Freitas, *Vice Chair*, Southwest Research Institute
R. L. Crane, *Secretary*, The American Society of Mechanical Engineers
B. F. Blackwell, Consultant
K. J. Dowding, Sandia National Laboratories
U. Ghia, University of Cincinnati
R. G. Hills, Sandia National Laboratories
R. W. Logan, Consultant
P. J. Roache, Consultant
W. G. Steele, Jr., Mississippi State University

Copyright © 2009 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.

CORRESPONDENCE WITH THE V&V 20 COMMITTEE

General. ASME Codes are developed and maintained with the intent to represent the consensus of concerned interests. As such, users of this Code may interact with the Committee by requesting interpretations, proposing revisions, and attending Committee meetings. Correspondence should be addressed to

Secretary, V&V 20 Committee
The American Society of Mechanical Engineers
Three Park Avenue
New York, NY 10016-5990

Proposing Revisions. Revisions are made periodically to the Code to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the Code. Approved revisions will be published periodically. The Committee welcomes proposals for revisions to this Code. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

Proposing a Case. Cases may be issued for the purpose of providing alternative rules when justified, to permit early implementation of an approved revision when the need is urgent, or to provide rules not covered by existing provisions. Cases are effective immediately upon ASME approval and shall be posted on the ASME Committee Web page.

Requests for Cases shall provide a Statement of Need and Background Information. The request should identify the Code, the paragraph, figure or table number(s), and be written as a Question and Reply in the same format as existing Cases. Requests for Cases should also indicate the applicable edition(s) of the Code to which the proposed Case applies.

Interpretations. Upon request, the V&V 20 Committee will render an interpretation of any requirement of the Code. Interpretations can only be rendered in response to a written request sent to the Secretary of the V&V 20 Committee. The request for interpretation should be clear and unambiguous. It is further recommended that the inquirer submit his/her request in the following format:

Subject:	Cite the applicable paragraph number(s) and the topic of the inquiry.
Edition:	Cite the applicable edition of the Code for which the interpretation is being requested.
Question:	Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. The inquirer may also include any plans or drawings that are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in this format will be rewritten in this format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME Committee or Subcommittee. ASME does not approve, certify, rate, or endorse any item, construction, proprietary device, or activity.

Attending Committee Meetings. The V&V 20 Committee regularly holds meetings, which are open to the public. Persons wishing to attend any meeting should contact the Secretary of the V&V 20 Committee.

Copyright © 2009 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.

INTENTIONALLY LEFT BLANK

Copyright © 2009 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.

STANDARD FOR VERIFICATION AND VALIDATION IN COMPUTATIONAL FLUID DYNAMICS AND HEAT TRANSFER

Section 1
Introduction to Validation Methodology

1-1 GENERAL

This Standard addresses verification and validation (V&V) in computational fluid dynamics (CFD) and computational heat transfer (CHT). The concern of V&V is to assess the accuracy of a computational simulation. The V&V procedures presented in this Standard can be applied to engineering and scientific modeling problems ranging in complexity from simple lumped masses to 1-D steady laminar flows to 3-D unsteady turbulent chemically reacting flows. In V&V, the ultimate goal of engineering and scientific interest is validation, which is defined as 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. However, validation must be preceded by code verification and solution verification. Code verification establishes that the code accurately solves the mathematical model incorporated in the code (i.e., that the code is free of mistakes for the simulations of interest). Solution verification estimates the numerical accuracy of a particular calculation. Both code and solution verification are discussed in detail in Section 2.

The estimation of a range within which the simulation modeling error lies is a primary objective of the validation process and is accomplished by comparing a simulation result (solution) with an appropriate experimental result (data) for specified validation variables at a specified set of conditions. *There can be no validation without experimental data with which to compare the result of the simulation.*[1] Usually a validation effort will cover a range of conditions within a domain of interest.

1-2 OBJECTIVE AND SCOPE

The objective of this Standard is the specification of a verification and validation approach that quantifies the degree of accuracy inferred from the comparison of solution and data for a specified variable at a specified validation point. The approach, proposed by Coleman and Stern [1], uses the concepts from experimental uncertainty analysis [2–4] to consider the errors and uncertainties in both the solution and the data.

The scope of this Standard is the quantification of the degree of accuracy of simulation of specified validation variables at a specified validation point for cases in which the conditions of the actual experiment are simulated. Consideration of solution accuracy at points within a domain other than the validation points (e.g., interpolation/extrapolation in a domain of validation) is a matter of engineering judgment specific to each family of problems and is beyond the scope of this Standard.

Fluid dynamics and heat transfer are the areas of engineering and science that are specifically addressed, but the validation approach discussed is applicable in other areas as well. Discussion and examples are centered on models using partial differential equations, but simpler models also fall within the purview of the validation approach.

1-3 ERRORS AND UNCERTAINTIES

Pertinent definitions from metrology are as follows:

(a) error (of measurement), δ: "result of a measurement minus a true value of the measurand" [5]

(b) uncertainty (of measurement), u: "parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand" [5]

These concepts were extended in reference [1] to apply to the value of a solution variable from a simulation as well as a measured value of the variable from an experiment.

In that context, then, an error, δ, is a quantity that has a particular sign and magnitude, and a specific error, δ_i, is the difference caused by error source i between a quantity (measured or simulated) and its true value. In the approach outlined in this Standard, it is assumed

[1] This is implicit in the phrase "real world" used in the definition of validation.

Copyright © 2009 by the American Society of Mechanical Engineers.
No reproduction may be made of this material without written consent of ASME.