Codes, Standards, Recommended Practices, and Guides of Engineering & Scientific Professional Societies: Application to Verification & Validation in Computational Engineering

Leonard E Schwer

Schwer Engineering & Consulting Services
6122 Aaron Court
Windsor CA 95492
Len@Schwer.net

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Summary

A review of American National Standards Institute (ANSI) accredited standards organizations with activities in the area of verification and validation (V&V) for engineering computations was performed. The primary organization are:

- American Institute of Aeronautics and Astronautics (AIAA)
- American Nuclear Society
- American Society of Mechanics Engineers
- European Research Community On Flow, Turbulence And Combustion (EUROFAC)

The pursuit of standards for V&V of engineering computations can perhaps be described as still in a conceptualization stage, i.e. standards have not yet been proposed. The present focus is on the predecessors of standards, viz. recommended practices and guides, with an emphasis on the more general guides.

This manuscript provides an overview of the professional society standards organizations and procedures. The various forms of documents: Codes, Standards, Recommended Practices, and Guides, associated with standards development are defined and differentiated.

Introduction

This manuscript has four main sections:

1. Introduction to standards and accreditation of standards organizations,
2. Overview of generic standards procedures adopted by the professional societies from the American National Standards Institute (ANSI) for the purpose of being accredited,
3. Summary of selected professional societies activities with standards procedures,
4. Description of professional societies activities in the area of verification and validation.

The majority of the material presented, and summarized, in this manuscript was sourced from the various professional society web sites, almost always without the benefit of quotation marks. Professional societies, with a role in standard procedures, have an obligation to be open about such policies and procedures, and the web provides a convenient way of communicating to their membership, and the broader community of interest.

A most useful standards introductory document is the American Society of Mechanical Engineers (ASME) “Introduction to ASME Codes and Standards,” a booklet written by the Task Group on Introduction to ASME Codes and Standards. The booklet, and associated video (not reviewed) are intended for engineering students, and are designed to make them aware of the role codes and standards may play in their future profession as mechanical engineers. Much of the Overview section material is taken from this source.

Why Standards

“The system of voluntary codes and standards has brought stability to the necessities of modern living.” The above cited ASME booklet provides this rather simple, but succinct, rational for standards. Virtually all modern manufactured products involve one or more engineering standards, which help to insure that parts fit together and can be replaced. Standards are an economic necessity for trade, especially in a global economy, where parts from many suppliers are assembled into a final product.

Standards are a vehicle of communication for producers and users. They serve as a common language, defining quality and establishing safety criteria. Costs are lower if products are standardized; training is also simplified. And consumers accept products more readily when they can be judged on intrinsic merit.

Who Makes Standards

The American National Standards Institute (ANSI) does not itself develop American National Standards (ANSs); rather it facilitates development by establishing consensus among qualified groups. The Institute ensures that its guiding principles -- consensus, due process and openness -- are followed by the more than 175 distinct entities currently accredited under one of the Federation’s three methods of accreditation: organization, committee or canvass. In 1999 alone, the number of American National Standards increased by nearly 5.5% to a total of 14,650 approved ANS. ANSI-accredited developers are committed to supporting the development of national and, in many cases international standards, addressing the critical trends of technological innovation, marketplace globalization and regulatory reform.

Legal and Practical Implications of Standards

The opinions in this section are the author's and need to be qualified by the following:

- The author is not qualified to offer any form of legal opinion.
- Common sense plus legal sense can equal nonsense.
- Anyone can sue anyone for anything at anytime.

Legal Implications

An important way in which a standard can help organizations conduct business is through the mutual agreement of the parties in a transaction to include a standard in their contract, as means of assuring a *minimal* level of performance, i.e. meets or exceeds the standard. This is in part why it is important for standards to also include a provision to verify compliance with stated requirements.

If a business contract includes a standard, the four possible outcomes, regarding the standard, are:

1. The standard was observed, and the results are satisfactory.
2. The standard was *not* observed, and the results are satisfactory.
3. The standard was observed, and the results were *not* satisfactory.
4. The standard was *not* observed, and the results were *not* satisfactory.

Case 1 is the optimal outcome, and no further legal action would be expected.

Case 2 is a sub-optimal outcome because even though the results were satisfactory, the contract requirement to comply with the standard was not met.

Case 3 implies that either the wrong standard was included, or that the included standard is inadequate. In the latter scenario, the professional society issuing the standard claims no liability, as the standards are voluntary. One hopes the associated standards committee would review the application of the standard.

Case 4 is the worst possible outcome and some recourse to compensation would be likely.

This simplified illustration also highlights how standards improve communication. Implied in the above is that the party receiving the results will be satisfied with the results, if the standard was observed. If there was no standard, both parties would have to develop and agree on terms that would form an ad hoc 'standard' for the purpose of forming a contract.

Practical Implications

A standard can translate into an economic force that sets *minimum* requirements.

As an illustration, consider two widget manufacturers, one makes widgets that comply with an appropriate standard and the other does not. It would be logical to assume the compliant widget costs more than the other, else the non-complaint manufacture would be at a double disadvantage. The customer has the choice of paying more for the compliant widget, or less for the non-compliant widget. The customer would apply some form of risk-and-reward analysis and purchase appropriately. Obviously, as the amount of risk increases, the value of the reward, i.e. lower cost, diminishes. Since it is only practical to develop standards in areas where there are significant risks, the non-complaint widgets would suffer a competitive disadvantage. As an example, would you consider the implantation of a non-compliant life saving medical device, over a complaint device, even if it was free?

In the area of computational mechanics, it would seem the practical implication of standards, or more likely best practices, will be to empower the user base of commercial software. In the current market between users (buyers) and vendors (developers) of commercial software there is no accepted common suite of benchmark or verifications problems that users can look to for assessing which of the vendor products might be best, i.e. price and performance comparisons. Certainly a user could create their own verification suite and ask vendors to provide performance comparison data, but it is likely that vendors would be reluctant to perform this service, unless the associated vendor labor was minimal compared to the expected license fee.

If a standards organization was to put forth a Best Practices document that contained a suite of verification problems, with a recommendation that the suite should be successfully performed before an analysis application (commercial code) was applied to a particular class of simulations, then performance comparisons would likely exist from vendors competing in this class of simulations. The vendors would also likely 'tweak' their codes to provide optimal performance for such a problem suite.

American National Standards Institute (ANSI)

The American National Standards Institute (ANSI) has served in its capacity as administrator and coordinator of the United States private sector voluntary standardization system for more than 80 years. Founded in 1918 by five engineering societies and three government agencies, the Institute remains a private, nonprofit membership organization supported by a diverse constituency of private and public sector organizations.

Organization

ANSI is a private, non-profit organization (501(c)3) that administers and coordinates the U.S. voluntary standardization and conformity assessment system.

Mission

The Institute's mission is to enhance both the global competitiveness of U.S. business and the U.S. quality of life by promoting and facilitating voluntary consensus standards and conformity assessment systems, and safeguarding their integrity.

Annual Budget

$16 million (approximate) with over 75 employees.

International Standardization

ANSI promotes the use of U.S. standards internationally, advocates U.S. policy and technical positions in international and regional standards organizations, and encourages the adoption of international standards as national standards where these meet the needs of the user community.

ANSI is the sole U.S. representative and dues-paying member of the two major non-treaty international standards organizations, the International Organization for Standardization (ISO), and, via the U.S. National Committee (USNC), the International Electrotechnical Commission (IEC).

Conformity Assessment

Conformity Assessment, the term used to describe steps taken by both manufacturers and independent third parties to assess conformance to standards, also remains a high priority for the Institute. ANSI's program for accrediting third-party product certification has experienced significant growth in recent years, and the Institute continues its efforts to obtain worldwide acceptance of product certifications performed in the U.S. and the promotion of reciprocal agreements between U.S. accreditors and certifiers.

One of the best indicators of the strength of the U.S. system is the government's extensive reliance on, and use of, private sector voluntary standards. Pursuant to OMB Circular A119, federal government agencies are required to use voluntary standards for regulatory and procurement purposes when appropriate. State and local governments and agencies have formally adopted thousands of voluntary standards produced by the ANSI Federation, and the process appears to be accelerating.

Professional Society Standards Procedures Overview

This overview is based on the standards procedures of the American Society of Mechanics Engineers (ASME) and American Institute of Aeronautics and Astronautics (AIAA).

Perhaps the most extensive (comprehensive) standards procedures are those of the Institute of Electrical and Electronics Engineers (IEEE) Standards Association, that includes a Companion publication with a subtitle of "Lessons Learned About the Standards Process," which is written in the form of a 'How To' manual.

Similar standards procedures documents exist for the American Society of Civil Engineers' (ASCE) Geo-Institute and ASCE's Structural Engineering Institute, each has their own Codes & Standards Council or Codes and Standards Activities Division, respectively.

Organization

Typically a society's standards organization reports directly to the society's board of governors. Depending on the extent of a society's standards activities, this standards organization may have a hierarchical structure. In the case of ASME, which has over 100 standards committees, the top level is the "Council on Codes and Standards" which oversees the operation of six standards developing supervisory boards and four advisory boards. The standards committees are then formed in functional and logical groups under these boards.

Forms of Committee-Generated Documents

It is the standards committees, comprising volunteer technical experts, that develop documents which can evolve into standards. The majority of these documents require a consensus of support by the committee members. Here consensus is defined by ANSI to mean substantial agreement, i.e. more than a simple majority, and requires that all views and objections be considered, with an effort made to resolve objections.

ASME has both codes and standards, but does not formally recognize AIAA's other (lesser) document formats of Recommended Practices, Guides, and Special Project Reports; AIAA has no codes.

Code

A code is a standard that has been adopted by one or more governmental bodies and has the force of law, or when it has been incorporated into a business contract.

Standards

Standards are considered voluntary, primarily because professional societies have no enforcement authority

Why then are standards effective? Standards are a vehicle of communication for producers and users. They serve as a common language, defining quality and establishing safety criteria.

AIAA Definition

Documents that establish engineering and technical requirements for processes, procedures, practices, and methods. Standards record the result of the consensus process conducted in accordance with the AIAA Standards Program Procedures. Standards also contain the provision necessary to verify compliance with stated requirements.

ASME Description

"A standard can be defined as a set of technical definitions and guidelines – 'how to' instructions for designers and manufacturers. Standards, which can run from a few paragraphs to hundreds of pages are written by experts."

Standards are considered voluntary because they serve as guidelines, not having the force of law. ASME publishes its standards; accredits users of standards to ensure that they are capable of manufacturing products that meet those standards, and provides stamps that accredited manufactures place on their products, indicating that a product was manufactured according to a standard. ASME cannot, however, force any manufacturer, inspector, or installer to follow ASME standards. Their use is voluntary.

Recommended Practices

Documents that contain authoritative engineering, technical, or design information and data relating to processes, procedures, practices, and methods. Recommended practices are the result of the consensus process and may evolve into standards through application and industry acceptance and are generally written in advisory language.

Guides

Documents that contain technical information in support of Standards and Recommended Practices. Guides provide instructions and data for the application of standards and recommended practices, procedures, and methods. Handbooks are in this category also preliminary standards and recommended practices. AIAA Guides are subject to the consensus process and are generally written in permissive language.

Special Project Reports

Documents that support or may lead to a standard, recommended practice, or guide. They may also be reports or documents resulting from a Standards Department contract including proposed government standards or specifications.

Only documents intended to be published as Special Project Reports are exempt from the consensus process. Annexes or rational statements which may have been circulated as Special Project Reports and which are later included as part of a consensus document must be subjected to approval procedures.

Committee Procedures

Codes and standards are living documents that are constantly revised to reflect new developments and technical advances. A request for development of a new code or standard may come from individuals, committees, professional organizations, government agencies, industry groups, public interest groups, or from a professional society division or section. The request is first referred to the appropriate supervisory board for consideration. If the board agrees there is a needed standards activity, they assigns the request to an existing committee, or determines that a new standards committee must be formed. Once an appropriate committee has concluded that there is sufficient interest and need, then the standards developing process is initiated.

The standards committee is composed of engineers with knowledge and expertise in a particular field. They represent users, manufacturers, consultants, universities, testing laboratories, and government regulatory agencies. The committee maintains a balance of members in various interest classifications so that no one group dominates. Volunteers must agree to adhere to professional society Policy on Conflict of Interest and the Engineer's Code of Ethics. Committee meetings must be open to the public, and procedures are used to govern deliberations and voting.

Voting procedures for the standards committees are designed to ensure consensus as defined by ANSI. Balloting is conducted at meetings and votes are also sent by mail and email. Repeated voting may be necessary to resolve negative votes. If an individual member feels that due process was not observed, appeals may be made to the standards committee, supervisory board, and subsequently, to the Board on Hearings and Appeals.

Once a consensus has been reached, the proposed standard is then subject to a public review. Anyone may submit comments during the public review period, to which the committee must respond. The draft is also submitted for approval to the supervisory board and ANSI. When all considerations have been satisfied, the document is approved as an American National Standard (ANS) and published by the professional society.

Consensus, Due Process and Openness

The guiding principals of the American National Standards Institute (ANSI) are consensus, due process and openness. Each standards committee has an obligation to comply with these principals, and the committee's supervisory body has the responsibility to ensure the committee fulfills these obligations. The key person in this area of compliance is the committee's Secretary, who is an employee of the professional society assigned to the standards committee with the responsibility to see that the committee operates under the society's policies and procedures for standards committees. Obviously there is considerable room for interpretation in any such collection of society policies and procedures, but the Secretary functions to assure that at least the intent of these policies and procedures are observed, and reports any blatant violations to the appropriate society supervisory group.

Consensus

Consensus is defined by ANSI to mean substantial agreement, i.e. more than a simple majority, and requires that all views and objections be considered, with an effort made to resolve objections. Any item put to a committee vote must pass by a consensus. Any cast negative ballot must be accompanied by a written statement explaining the cast negative. In the event that the cast negative votes are in a simple minority, an effort to remove the cast negative votes, and objections, is required of the majority. The documentation provided by the cast negatives, any responses, and subsequent changes in votes become part of the approved item, and is forwarded to the responsible review group, and eventually ANSI.

Due Process

If an individual member feels that due process was not observed, appeals may be made to the standards committee, supervisory board, and subsequently, to the Board on Hearings and Appeals.

Openness

Of the three ANSI principals, perhaps the most important to the successful operation of the committee is openness. The minimum requirement for openness appears to be holding open committee meetings and announcing the meeting in an appropriate forum such as professional society publications, e.g. ASME's *ME Magazine*.

However, because the committee attempts to represent the entire community, e.g. computational mechanics, and seeks to propose documents that represent a consensus of this community, it is incumbent upon the committee to present the committee's activities in appropriate forums. It is the author's opinion that there is no such thing as too much openness in standards activities, and that the committee needs to make 'advertising' its activities a priority.

Examples of things a committee can do to improve openness:

- Dedicated committee web site that contains items such as: document drafts, meeting announcements and agendas, minutes of past meetings, and future activities.
- Open email distribution lists so interested others may participate in committee discussions conducted via email.
- Encouraging participation in committee activities by non-members. Committee membership is typically limited, e.g. 30 voting members, but any interested individual may contribute to the committee.
- Organization of symposia, in appropriate technical forums, to present developing documents and ideas, for the purpose of soliciting feedback.
- Presentation of short courses intended to help educate those new to the standard activity area.

Initiation of a Standards Activity Committee

This section draws on the author's recent experience in forming a standards committee; ASME Performance Test Codes #60 Committee on Verification and Validation in Computational Solid Mechanics. Standards activities, including forming committees, can be initiated by professional societies to meet a need, or groups can petition professional societies to form a standards committee; it is this latter option that will be discussed.

Ad Hoc Committee Formation

When an individual, or group, recognizes a need for a standards activity they should first survey the appropriate professional societies for related existing standards activities. Assuming no such standard committee activity already exists, an ad hoc committee should be formed to pursue creation of a new standards committee. An individual may also petition to start a new committee, but the advice and support of interested others, plus the implied wide spread acknowledgement of the standards need of a group proposal, as apposed to an individual, makes the ad hoc committee approach more attractive to professional society reviewing groups.

The method of selecting members of the ad hoc committee is arbitrary, but the committee guidelines of the targeted professional society should be consulted for guidance on both the balance and number of members. Since most standards apply to manufactured products, the society's desired balance is often expressed in terms of producers and users. In the case of the V&V Committee, the categories of industry, government, and academia seemed more appropriate, and are sometimes quoted as standards committee categories by professional societies.

In the present example, the selection of ad hoc committee members was a 'bootstrap' operation. A small motivated core of members, four in this case, selected areas of computational solid mechanics, and V&V, that would needed to be represented on the committee, e.g. experimental mechanics, non-determinism, and commercial code developers, and then produced a list of candidates for each area and balanced membership category. At some point as the number of members of this ad hoc committee grows, the decision of who to invite to join the ad hoc committee moves from the small core group to the existing membership.

Petition to Form a Standards Committee

The purpose in forming an ad hoc committee is to petition the target professional society to form a standards committee. This requires drafting a suitable petition, again the targeted professional society guidance for such petitions should be consulted.

The petition is also the committee's first experience with developing a consensus document, i.e. a document acceptable to all with at most only minor reservations. The process of developing a draft petition mimics the process that the committee will mostly use in drafting other consensus documents. A small group, 2 to 4 members, are tasked with providing a draft for comment by the full committee. In the case of a relative small document like the petition, a lead author provides an initial draft and the others members of the small group work to improve the draft. When the small group is satisfied with its efforts the draft petition is circulated among the full membership of the ad hoc committee for comment and subsequent revision. After the revisions are incorporated, and all major objections have been resolved, the document is submitted to the ad hoc committee for an approval vote.

The petition should address key questions such as:

- Identification of need for a new standard.
- Why is a standard the proper solution?
- Who is the identified user of the standard?
- Does a technical base exist for developing a standard?
- Is there a broad constituency for use of the standard?

An example of a standards committee petition, for the subject ASME V&V Committee, is available on the web at the URL: www.usacm.org/vnvcsm/standards_request.htm. in this particular case, the petition was made by an ad hoc committee formed under another professional society, the United States Association for Computational Mechanics (USACM). The USACM is not accredited by ANSI and thus sought formation of this activity under an ANSI approved professional society. The support of USACM for the petition to ASME was probably another positive factor in their consideration of the petition.

Submission of the Petition and Review

The petition to form a new standards activity is usually submitted to the highest level in the professional society's standards organization. They then decide where to direct the petition, i.e. which board or existing committee, and may request a representative of the ad hoc committee to make a formal presentation and provide answers to questions about the petition.

The board, or committee, designated to review the petition will most likely request a representative of the ad hoc committee to make a formal presentation, and provide answers to questions about the petition. This review group will then decide if the petition is appropriate for its general area of expertise, or recommend the petition be submitted to another review group, or possibly reject the petition. If they accept the petition for review, it is circulated among their members for comments and questions. After an appropriate discussion, the review group votes to accept or reject the petition. This is a consensus vote and cast negative ballots must be accompanied by written reasons for the negative vote. The objections should be addressed by the ad hoc committee in an effort to have the cast negative vote formally withdrawn. If a positive consensus is reached, the review group recommends to the governing body that the petition be accepted.

A statement of the proposed committee's charter and membership roster should be included with the petition. Both will need to be approved by the review committee and it is easier to do all this with one vote of the review group.

After the Petition

During the review and acceptance period, which can take several months, the ad hoc committee should work to establish rules of operation, including procedures for nominating and electing future members. These should be drafted to comply with existing professional society procedures and policies for standards committees. These document are also consensus documents and require review and approval by the ad hoc committee, or approved newly formed standards committee.

An example of an "Organization and Membership Policy" document, for the subject ASME V&V Committee is available on the web at the URL:

www.usacm.org/vnvcsm/Membership/org&membership.htm

Selected Professional Engineering Societies with Standards Procedures

The list of ANSI member organizations was scanned for organizations that might have standards that could reasonably be expected to include verification and validation of engineering software.

American Institute of Aeronautics and Astronautics (AIAA)

Accredited by the American National Standards Institute (ANSI), AIAA provides national and international aerospace standards publications. AIAA standards activities are conducted through Committees on Standards (CoS), which are supervised by the Standards Executive Council. Anyone is invited to examine and comment on draft AIAA products that are nearing completion through the Public Review process.

The AIAA Standards Program consists of a process that produces voluntary aerospace standards, guides, and recommended practices. These standards are formulated and written by experts who freely contribute their time and effort to develop standards documents in the national interest, where the need for such standards documents is identified. AIAA approved standard documents are advisory only. Their use by anyone engaged in industry or trade is entirely voluntary.
(www.aiaa.org)

American Nuclear Society

Formed in 1957, the ANS Standards Committee has been active in the development of industry standards ever since. All ANS Standards receive dual approval from the American National Standards Institute and are thus considered American National Standards.

Since its start, ANS has written and approved over 100 different standards, and numerous versions of many of those. At present ANS has 90 standards that are current American National Standards and many others that are considered historical standards. These technical documents are written, reviewed, and approved by the army of talented volunteers that support the program. ANS has over 1,000 volunteers who provide their experience and expertise to the various levels of standards committees to see that these important documents are written for the industry's needs.
(www.ans.org)

American Society of Mechanical Engineers (ASME)

Since 1884, when the first performance test codes were developed, ASME International has pioneered the development of codes, standards and conformity assessment programs. ASME maintains and distributes 600 codes and standards used around the world for the design, manufacturing and installation of mechanical devices.

The Council on Codes and Standards is one of five councils that report to the ASME Board of Governors. Under the this council there are six standards developing supervisory boards and four advisory boards that manage over 100 committees with 4000 volunteer members.

ASME is one of over 200 volunteer organizations in the United States that adhere to the procedures accredited by the American National Standards Institute (ANSI) for the development of standards. These procedures must reflect openness, transparency, balance of interest, and due process.
(www.asme.org)

ASTM International

Founded in 1898, ASTM International is a not-for-profit organization that provides a global forum for the development and publication of voluntary consensus standards for materials, products, systems, and services. Over 30,000 individuals from 100 nations are the members of ASTM International, who are producers, users, consumers, and representatives of government and academia. In over 130 varied industry areas, ASTM standards serve as the basis for manufacturing, procurement, and regulatory activities. Formerly known as the American Society for Testing and Materials, ASTM International provides standards that are accepted and used in research and development, product testing, quality systems, and commercial transactions around the globe. Standards are published in the Annual Book of ASTM Standards
(www.astm.org)

American Society of Civil Engineers (ASCE)

The ASCE has two institutes, each with their own codes and standards organizations.

Geo-Institute

The purpose of the Geo-Institute Codes and Standards Council (CSC) is to further the mission of the Geo-Institute. CSC will provide leadership within the Geo-Institute on public policy issues related to geo-applications in the form of standards and consensus guidelines/practices. CSC will establish the Geo-Institute as the premier geotechnical codes and standards developing organization serving the profession and the public at large.
(www.geoinstitute.org/codes_standards.html)

Structural Engineering Institute

Codes and Standards Activities Division (CSAD) coordinates all activities of ASCE related to the establishment, use, or discontinuance of standards in the area of buildings.
(www.asce.org/instfound/sei_committees.cfm)

Institute of Electrical and Electronics Engineers (IEEE)

The IEEE Standards Association (IEEE-SA) is a membership organization that produces standards that are developed and used internationally serving today's industries with a complete portfolio of standards programs.

The IEEE-SA has two governing bodies: the Board of Governors and the Standards Board. The Board of Governors is responsible for the policy, financial oversight and strategic direction for the Association including two very important documents:

1. IEEE Standards Association Bylaws
2. IEEE Standards Association Operations Manual

The Standards Board has the charge to implement and manage the standards process, such as approving projects.
(standards.ieee.org/)

Society of Automotive Engineers (SAE)

The SAE Technical Standards Board (www.sae.org/technicalcommittees/tecstand.htm) is the largest developer of technical standards for land, sea, air, and space. Industry, government, and the public are served by standards that are used for design, manufacturing, testing, quality control, and procurement.

SAE publishes many new, revised, and reaffirmed standards each year in three categories: Ground Vehicle Standards (J-Reports); Aerospace Standards; and Aerospace Material Specifications (AMS). Access to this up-to-date information is a key component of efficient product design, testing and operation. Because standards are an agreement on form, fit and function, they enable industries, engineering disciplines, and entire countries to talk to each other in a common language.

Professional Societies with Verification & Validation Activities

American Institute of Aeronautics and Astronautics (AIAA)

AIAA has at least two activities related to software Verification and Validation: a standards committee on computational fluid dynamics, and a working group on software reliability.

Computational Fluid Dynamics Committee on Standards

Scope: Standardization in the field of computational fluid dynamics (CFD) for the purpose of promoting improvement in efficiency and productivity.

Chairman: Raymond Cosner (raymond.r.cosner@boeing.com)

In 1998 this Committee published a consensus guide on V&V in CFD:

"Guide to Verification and Validation of Computational Fluid Dynamics Simulations"
(G-077-1998)

Abstract

"This document presents guidelines for assessing the credibility of modeling and simulation in computational fluid dynamics. The two main principles that are necessary for assessing the credibility are verification and validation. Verification is the process of determining if a computational simulation accurately represents the conceptual model, but no claim is made of the relationship of the simulation to the real world. Validation is the process of determining if a computational simulation represents the real world. This document defines a number of key terms, discusses fundamental concepts, and specifies general procedures for conducting verification and validation of computational fluid dynamics simulations. The document's goal is to provide a foundation for the major issues and concepts in verification and validation. However, this document does not recommend standards in these areas because a number of important issues are not yet resolved. It is hoped that the guidelines will aid in research, development, and the use of computational fluid dynamics simulations by establishing common terminology and methodology for verification and validation. The terminology and methodology should also be useful in other engineering and science disciplines."

This rather brief guide, 19 numbered pages, at first reading appears to be rather simple in scope and depth. However, after several readings, over the past three years, and a much expanded appreciation of the subtleties of V&V, this guide is now regarded by the author as a touchstone for similar efforts to provide guidance in V&V. This guide a great starting point for learning about V&V, and its 105 referenced works provide further guidance on specific topics in V&V

and CFD. As an indication of the effort required to develop a consensus document, it took the Committee about 6 years to produce the guide.

AIAA Software Reliability Working Group

AIAA is in the process of negotiating a means to revise and update the "Recommended Practice for Software Reliability" in cooperation with the IEEE Reliability Society.

"Recommended Practice for Software Reliability." (ANSI/AIAA R-013-1993)

Contact: James E. French (jimf@aiaa.org)

Abstract

"This recommended practice describes an approach to estimating and predicting the reliability of software. It provides information necessary for the application of software reliability measurement to a project, lays a foundation for building consistent methods, and establishes the basic principal for collecting the performance data needed to assess the reliability of software. The document describes how any user may participate in on-going, software reliability assessments or conduct site or package specific studies."

American Nuclear Society

The American Nuclear Society has a division with responsibility for computing practices standards and has published a guide on verification and validation of scientific and engineering computer programs.

Mathematics & Computation Division

(mcd.ans.org)
Chair: Richard Sanchez (richard.sanchez@cea.fr)

Division members promote the advancement of mathematical and computational methods for solving problems arising in all disciplines encompassed by the Society. They place particular emphasis on numerical techniques for efficient computer applications to aid in the dissemination, integration, and proper use of computer codes, including preparation of computational benchmarks, and development of standards for computing practices, and to encourage the development on new computer codes and broaden their use.

Guidelines for the Verification and Validation

"Guidelines for the Verification and Validation of Scientific and Engineering Computer Programs for the Nuclear Industry," ANSI/ANS-10.4-1987; R1998, ANS Order # 240150 ($60.00).

This document provides guidelines for the verification and validation of scientific and engineering computer programs developed for use by the nuclear industry. The main feature of this document is a number of detailed checklists for each phase of the described V&V process:

- Verification of Requirements
- Verification of a Test Plan
- Verification of a Design
- Verification of Source Code
- Verification of Program Integration
- Program Validation
- Verification of Test Results
- Verification of the Installation Package

American Society of Mechanical Engineers (ASME)

The American Society of Mechanical Engineers has a standards committee for verification and validation in solid mechanics, and a Fluids Engineering Division committee active in verification and validation issues in computational fluid mechanics.

Board on Performance Test Codes #60 - Committee on Verification and Validation in Computational Solid Mechanics

(www.asme.org/cns/departments/performance/public/ptc60/ and www.usacm.org/vnvcsm/)

Chair: Len Schwer (Len@Schwer.net)

Charter: To develop standards for assessing the correctness and credibility of modeling and simulation in computational solid mechanics.

In August 1999, the United States Association for Computational Mechanics (USACM) recognized the need for assessing the credibility of computational solid mechanics simulations and set as a goal the establishment of standards by which the credibility of computational solid mechanics simulations can be assessed. That effort led to the formation of the ASME Standards Committee on Verification and Validation in Computational Solid Mechanics, in September 2001.

The Committee is currently working on developing two documents:

1. "Definitions and Terminology"
2. "Elements of V&V"

The latter is intended to provide an overview of the V&V process, similar to the AIAA Guide, and includes sections on modeling, verification, and validation.

The Committee has also produced eight Special Topic Reports:

1. Calibration in Computational Mechanics
2. A Posteriori Error Estimation
3. Experimental Data Requirements
4. Non-Determinism Requirements
5. Benchmarks
6. Constitutive Model V&V
7. Constitutive Model V&V for Softening Materials
8. Sargent Circle with Terms & Concepts

as part of their effort to define the scope of the issues that need to be addressed in verification and validation in computational solid mechanics.

ASME Fluids Engineering Division

The Coordinating Group on Computational Fluid Dynamics was formed in 1988 to address fluid dynamics issue related to computations.

Coordinating Group on Computational Fluid Dynamics

www.asme.org/divisions/fed/committees/cgcfd.html

Chair: Urmila Ghia (urmila.ghia@uc.edu)

The Coordinating Group on Computational Fluid Dynamics (CGCFD) serves as a focal point for technical activities in the areas of computational methods (finite-difference, finite-volume, finite-element) for solving various approximate governing equations of fluid flow, novel algorithms for solving flow problems on advanced computer architectures (massively parallel and cluster of workstations), benchmarking of public domain and commercially available software, numerical simulation of flow problems in industry, and application of CFD techniques to other related disciplines, for example multiphase flows, hydrodynamics, acoustics, etc. CGCFD members cooperate to organize and promote symposia and forums in these areas and with members of the other technical committees and coordinating groups to co-sponsor activities of mutual interest. CGCFD also organizes panel discussions on topics of current interest.

The Group has successfully advocated the adoption of an editorial policy statement, for the Division's primary technical journal, on the control of numerical accuracy:

"Editorial Policy Statement on the Control of Numerical Accuracy," by C.J. Freitas, *Journal of Fluids Engineering*, Volume 115, pages 339-340, September 1993.

A key feature of this policy is the *requirement* for authors to provide grid convergence studies for all numerical results.

Currently, the Group's Verification, Validation and Uncertainty Committee, is developing a procedure (two methods) for computing the magnitude of uncertainty in a calculation. This procedure for the reporting of uncertainty will be added to the 2002 update of the Journal of Fluids Engineering Policy Statement.

ASTM International

ASTM International has several Standard Guides that relate to models for fire, ground-water flow, and air quality.

As an example, the "Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models," (Designation E 1355-97) provides 4.5 pages of specific items that should be included in the evaluation. Topics covered include:

- Model Scenario Definitions
- Mathematical and Numerical Robustness
- Model Sensitivity
- Model Evaluation
- Evaluation Report

A related publication, "Standard Guide for Determining Uses and Limitations of Deterministic Fire Models," (Designation E 1895-97) provides guidance for model users, developers, and the authority having jurisdiction.

These documents are written using terminology familiar to those active in V&V, and could serve as a template for other similar guides.

European Research Community On Flow, Turbulence And Combustion (EUROFAC)

(www.ercoftac.org)

Vision Statement: To be the leading European association of research, education and industry groups in the technology of flow, turbulence and combustion.

Mission Statement: Within Europe:

- To define a strategy for research, education and exchange of information in flow, turbulence and combustion, with the aim of improving quality of life and the generation of wealth.
- To strengthen the research base and to improve the quality and relevance of its output to industry and government.
- To provide members with access to all sources of useful information on flow, turbulence and combustion.

- To be influential with funding agencies, governments and the European Commission and Parliament.
- To be a focus for contact with non-European groups.

Special Interest Group 101: Quality and Trust in Industrial CFD (IAC SIG)

(www.ercoftac.org/SIGs/SIGQT.html)

The Special Interest Group (SIG) on Quality and Trust in the Industrial Application of Computational Fluid Dynamics was formally inaugurated at the first European Meeting of the SIG in Paris on October 8th 1997. The SIG adopted three clear program objectives, summarized below:

1. The first is the production of Best Practice Guidelines (BPG). These will constitute generic advice on how to carry out quality CFD calculations. They will therefore address mesh design; construction of numerical boundary conditions where problem data is uncertain; mesh and model sensitivity checks; distinction between numerical and turbulence model inadequacy; preliminary information regarding the limitations of turbulence models etc.. The aim is to encourage a common best practice by virtue of which, separate analyses of the same problem, using the same model physics, should produce consistent results.
2. The second objective is the production of Application Procedures (AP). This will comprise a compilation of CFD calculations of a range of test cases chosen for their industrial/end-user interest, and carried out according to the Best Practice Guidelines. For each test-case, the performance of various turbulence and associated models will be analyzed, bounds quantified, and advice proffered on which calculated flow parameters can or cannot be trusted.
3. The third objective is the implementation of a sophisticated database. This will embody the Application Procedures and will enable the procedures to be searched and browsed. In particular it will facilitate graphical display of user selected parameters/fields and allow comparisons between these drawn either from experimental or calculated data within the Application Procedures or, if desired, data supplied by the user.

The program will comprise two phases. Phase-1, lasting up to one year, will produce the Best Practice Guidelines, elicit and assemble a compendium of flow regimes of industrial interest from each sector, and, from this compendium, identify those flow classes which are generic across industrial sectors. That is, a “bottom up” process will be pursued to produce a generic taxonomy. In parallel, during this first year, the prototype database will be implemented and tested. Phase-2, lasting up to three years, will deliver the first issue of the Application Procedures and incorporate this into the database.

Best Practices Guidelines, Version 1.0, was issue in January 2000. The cost is 100 Euros for non-ERCOFTAC members.
www.ercoftac.org/SIGs/BPG.html

Institute of Electrical and Electronics Engineers (IEEE)

The IEEE Standards Association (IEEE-SA, http://standards.ieee.org/) is a very large ANSI accredited standards organization. While it has a preeminent role in computer software standards, it is the author's perception that the focus is on the 'software engineering' aspects of software standards, rather than the 'engineering mechanics' aspect of the other included professional societies.

IEEE Standard for Software Verification and Validation 1998 (1012-1998)

This IEEE Standards product is part of the family on Software Engineering. Software verification and validation (V&V) processes, which determine whether development products of a given activity conform to the requirements of that activity, and whether the software satisfies its intended use and user needs, are described. This determination may include analysis, evaluation, review, inspection, assessment, and testing of software products and processes. V&V processes assess the software in the context of the system, including the operational environment, hardware, interfacing software, operators, and users.(ISBN 0-7381-0196-6, IEEE Product No. SH94625-TBR, $102)

Society for Computer Simulation International

The Society for Computer Simulation International is the principal technical society devoted to the advancement of simulation and allied computer arts in all fields. The purpose of the Society is to facilitate communication among professionals in the field of simulation. To this end, the Society organizes meetings of regional councils, sponsors and cosponsors national and international conferences, and publishes the monthly technical journal SIMULATION as well as the quarterly journal TRANSACTIONS of The Society for Computer Simulation.
(www.scs.org)

Although not an ANSI accredited organization, SCS has an interest in verification and validation.

Contact: Vince Amico (amico@cs.ucf.edu)

Unites States Association for Computational Mechanics (USACM)

The Association serves as a formal vehicle for overseeing and coordinating conferences, colloquia, symposia, and other technical meetings, and it promotes research, commercial and academic activities in the general area of computational mechanics that take place within the United States.
(www.usacm.org)

Although not an ANSI accredited organization, USACM has an active, and sincere, interest in verification and validation. USACM is well represented on the above described ASME PTC #60 Committee on Verification & Validation. Also, through the publication of USACM's parent organization, the International Association for Computational Mechanics (IACM), activities of the USACM, including V&V, are reported to the international membership.

Contact: Len Schwer (Len@Schwer.net)

Thoughts on Future Directions of V&V and Standards

In presentations on verification & validation, and in particular what the ASME V&V Committee is attempting, the audience feedback I receive is very positive, and quite encouraging; I also assume those that think I am wasting my time do not bother to waste their time telling me so. The most common reaction is "I am glad someone is working on V&V standards." This is usually from an engineer that has tried to deal with answering the question, "How valid are those results?" either for personal satisfaction, or more typically, to answer this question as posed by management. The enthusiastic support for V&V standards is significantly diminished with the realization that we are probably years away from even a Best Practices publication, yet alone any standards.

To understand this enthusiasm for V&V standards, I think it helps to look at what I believe are some important trends, related to computational mechanics, as an illustration of the need for V&V standards:

- Less Physical Testing – as the cost of computing declines, dramatically, relative to the cost of maintaining a high quality testing facility, there is increasing economic pressure to "just do some calculations."
- Increased Product Liability – in an increasing litigious society, failure to take reasonable precautions to ensure product safety can have serious economic consequences. Combine this need to do 'something,' with the above lack of quality testing facilities, and the result is "just do some calculations."
- Increased Self-Certification – Regulatory agencies typically put the burden of proof for certification on the manufacturer, e.g. auto companies for crash safety and biomedical device manufactures for fault tolerant operation in vivo. For economic reasons, perhaps not all required test configurations are tested, and, in the latter example, limited access to testing 'facilities' for biomedical devices, both place an emphasis on "just do some calculations."
- From Developer/Analyst to Black-Box/User – Less than 20 years ago, most analyses were performed by the same person that wrote the analysis code, or worked in the same group with the code developer. Today, almost all analyses are performed using commercial software, where even a trusted user is not allowed to access the source code, for verification, or any other, purpose. The most ardent user is forced to 'know' the analysis package through its user documentation, which ranges from at best good to too often nonexistent.

As more emphasis is placed on using computational mechanics to replace testing, and the corresponding computation results have greater economic, and safety, consequences, management will more frequently ask “How valid are those results?” and enlightened management will require an informed and measured answer.

As of this writing, it seems the path forward to V&V standards will involve dissecting computational mechanics into its basic parts and then writing Best Practices, and hopefully standards, for these basic parts. The immediate challenge is how to dissect such a topic where many of the parts are interrelated; the surgeon’s task of separating Siamese twins comes to mind. A logical approach would be to select those areas of computational mechanics that can be isolated relatively easily, e.g. error estimation and constitutive modeling, and attempt Best Practices documents for those areas. But the emphasis in this approach will of necessity be on verification, as validation requires the whole of computational mechanics to perform adequately.

The most pressing need in V&V is validation, this is not to ignore verification, but for the reasons cited above, practical guidance, in nearly any form, on validation must be given a priority; certainly verification and validation can proceed in parallel. There seems to be three key areas in validation that guidance needs to be communicated to analysts, and their managers, immediately:

1. Precision Testing – what is required to specify and perform experiments that will be meaningful and useful for validation.
2. Validation Metrics – how do we quantify the comparisons between measurement and simulation results.
3. Role of Non-Determinism – neither the observed nor simulated behavior is known with certainty, e.g. due to randomness in the physical system and modeling idealizations, this further complicates the validation process.

It is my belief that guidance in these three areas of validation needs to be presented in a form that provides for both education and guidance. Validation Metrics are a new area of research and development and thus require education to disseminate the results. Most analysts will have some training in the area of Non-Determinism, fewer will have the sophisticated working knowledge needed to make the required validation assessments.

The most dire need for validation education is in the area of experimental mechanics, and especially precision testing designed for validation. The demise of almost any form of laboratory training in universities produces analysts with strong theoretical, and numerical, skills but a complete lack of knowledge of experimental mechanics. The other side of the precision testing ‘coin’ are those diminishing number of practicing experimental mechanicians. Because of the traditional separation of computations from experiments, it is rare to find an experimentalist with an understanding of the requirements of precision testing for validation. This lack of knowledge, on both sides, needs to be bridged with a sharing of knowledge.

Finally I would comment that the *European Research Community On Flow, Turbulence And Combustion* (EUROFAC) appears to be developing a very sensible, and economic, method of operating a verification and validation organization. The pooling of scarce resources to form subscriber based (fee), or perhaps free, collections of verification benchmarks and sample cases, and possibly data from past validation efforts, is a key to the future success of V&V.

Currently it seems only the Government can afford the financial burden of full V&V programs, but the author wonders if even this source of funding is adequate to the most difficult task they are attempting. Efforts to provide V&V guidance, or standards, will not be widely accepted if the cost associated with implementing them is excessive. One way to lower these cost is to develop databases of common interest V&V data, so that each organization does not have to pay to (re)produce the data. The business model for this type of operation is probably a non-profit organization funded by subscriptions and Government support.

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