Background

The original focus of the SEM on experimental techniques has progressively evolved for the past twenty years to include Modeling and Simulation (M&S) in a broad sense. Examples include the large numbers of organized sessions and publications at the International Modal Analysis Conference (IMAC) and SEM Annual Conference on Experimental and Applied Mechanics that address modeling techniques in structural dynamics and mechanics, model fitting methods, data processing algorithms, etc. This trend is to be paralleled with the fact that the scientific community has witnessed an exponential increase in recent years in the number of small-size conferences and workshops dedicated to the promotion of modeling and numerical methods. Examples include meetings on multi-scale modeling, material modeling, nano-technologies, meshless methods, simulation sciences, etc.

Because the scientific method in physics and engineering has embraced M&S and problem resolution now depends to a great extent on the development of a predictive capability (as opposed to testing alone), the credibility of numerical simulations must be established. This is accomplished through various activities collectively referred to as Verification and Validation (V&V), which includes the thorough quantification of uncertainty and its effect on predictions.

A Technical Division dedicated to Model Validation and Uncertainty Quantification (MVUQ) is beneficial for several reasons:

- We strongly believe that there is no validation without data. Because of their expertise with testing, calibration, and the quantification of measurement error, test engineers can play a central role in the definition of validation experiments. A professional or technical society dedicated, like SEM, to experimental techniques (as opposed to one that focuses on theory or simulation alone) can play a leading role in the definition and promotion of model validation.

- The MVUQ Technical Division organizes a visible and coherent effort on behalf of SEM in the area of model validation for structural dynamics and engineering mechanics.

- The SEM-sponsored IMAC is recognized for the forum it offers on model validation. Model validation-related sessions have been developed at the IMAC for the past seven years (1999-2005). The single session in 1999 grew to several sessions to reach six, or 33 technical papers and short tutorials, in 2005. The MVUQ Technical Division helps to keep this effort going. It also develops other activities such as technical sessions at other conferences, educational opportunities, and workshops dedicated to model validation.

- The SEM has always been very pro-active regarding its educational role. Because V&V is multi-disciplinary and draws on testing, modeling, statistics, and information theory, education must play a significant role if V&V is to impact the way engineers perform validation experiments and numerical simulations. There is currently a demand by companies of the private sector, as well as national laboratories, for MVUQ related tutorials and short-courses. With the goal of promoting best model validation practices within the industry, it makes sense to promote model validation within the SEM.

- Other professional and technical societies, such as the American Institute of Aeronautics and Astronautics (AIAA), American Society of Civil Engineers (ASCE), American Society of Mechanical Engineers (ASME), and US Association of Computational Mechanics (USACM), have started to actively pursue the theme of model validation. Examples are the non-deterministic forum (that will become a full conference in 2005) of the AIAA Structures, Structural Dynamics, and Material Conference; the ASCE Probabilistic Mechanics Conference and its many sessions dedicated to model validation; the ASME PTC-60 Standards committee on V&V in Solid Mechanics; and the MVUQ related sessions organized at meetings of the USACM. The mandate of the MVUQ Technical Division includes coordinating activities with other professional or technical societies.

Why model V&V?

The scientific method of formulating a hypothesis, developing an experiment and collecting information, and reaching a conclusion either in favor of the hypothesis or that contradicts it, has traditionally been based on physical experiments and measurements. Compared to the 4,000+ years of scientific history, science-based predictive Modeling and Simulation (M&S) is recent. Only since the late 1980's, or for the past twenty years or so, have scientists started to be confident in their ability to understand and model moderately complex phenomena or applications.

The consequence is that physical experiments that have traditionally supported the decision-making process in physics and engineering are progressively being replaced by numerical simulations. The availability of increasingly faster, cheaper, and massively parallel computing resources are feeding this trend, together with the development of more powerful computing languages and user-friendly visualization tools. It also goes hand-in-hand with the economic imperative of reducing time-to-market cycles and research and development costs, a promise that many industries claim the increased reliance on M&S can fulfill.

One dramatic example where M&S replaced testing is the certification by Boeing Aerospace of their 777 aircraft, which was to a great extent based on simulations in the late 1990's even though the U.S. Federal Aviation Administration still required full-scale testing for its own accreditation. Accrediting the aircraft involved performing large-scale computational fluid dynamics simulations of its flutter characteristics. Another example is the Nuclear Test Ban Treaty enforced in the United States since 1992, which makes nuclear testing impossible. Mathematical models, computer codes, and numerical simulations have been developed at national laboratories of the U.S. Department of Energy to study the performance, reliability, and provide the annual certification of these very complex systems.

Because the scientific method in physics and engineering has embraced M&S and problem solving increasingly depends on the development of a predictive capability, as opposed to testing alone, the credibility of numerical simulations must be established. This is accomplished through various activities collectively referred to as model verification and validation. V&V is a rigorous and scientifically sound methodology to assess the prediction accuracy of models and numerical simulations. Confidence in predictions results from the breath and outcome of V&V activities.

What does V&V consist of?

V&V activities include, but are not restricted to, the design of validation experiments; code verification; calculation verification; the design of computer experiments; response feature extraction; statistical screening and classification; surrogate modeling; uncertainty modeling, propagation, and quantification; test-analysis correlation; model calibration and updating; and the assessment of prediction accuracy.

Uncertainty Quantification (UQ) plays a central role in V&V because the assessments of experiments, codes, calculations, models, and numerical simulations are generally made in terms of quantifications of errors and uncertainties. UQ also provides the missing link between the assessment of prediction accuracy, provided by the activities of V&V, and methods for decision-making under uncertainty, such as reliability and robustness analyses. Decision-making under uncertainty is another area that currently undergoes significant interest and research in engineering and physics.

Typical questions that V&V can answer …

- Why should we believe that the predictions of our numerical simulations are any better than crystal-ball reading?
- What is the prediction accuracy of the model, especially away from those settings that can be measured experimentally?
- What is the validation domain for a given application?
- Is the computer code free of programming mistakes?
- Does the computational mesh (or grid) provide converged solutions?
- Which feature of the response best provides physical insight about the phenomenon?
- Where is an observed variability coming from?
- Which parameters of the numerical simulation control the "spread" of output results?
- What is the effect of modeling uncertainty on the predictions?
- Can the physics-based simulation be replaced by a fast-running surrogate?
- How to meaningfully compare physical measurements to numerical predictions?
- Where is the modeling error coming from, and how can it be reduced?
- Which numerical modeling technique is better for a particular application?
- How robust are predictions to the modeling error?
- How to study the trade-offs between prediction accuracy and modeling lack-of-knowledge?