An Overview of ASME V&V 20: Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer

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OUTLINE

- **Origin of the approach; background**

- **ASME V&V 20 -- Overview**

Origin of this V&V Approach

- US Office of Naval Research Program 1996-2000 – Produce a "documented solution"
  - Could unsteady RANS research codes be implemented with confidence in the design of the next generation of naval vessels?
  - Experiments on models in 3 towing tanks in U.S. (David Taylor, IIHR) and Italy (INSEAN)
  - Two RANS codes used by (a) code developers and (b) other groups
  - Classified program
- A quantitative V&V approach was proposed based on error and uncertainty concepts in experimental uncertainty analysis (ISO GUM, 1993, international standard).
  - Hugh Coleman (UAHuntsville) and Fred Stern (Iowa) published initial version in ASME Journal of Fluids Engineering, Dec 1997.

V&V 20 Development

ASME Performance Test Codes Committee PTC 61:

V&V 20: Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer

Approach is based on experimental uncertainty analysis concepts of error and uncertainty. Committee formed in 2004; Draft document completed; peer review comments received early June 2008; publication probable in late 2008.

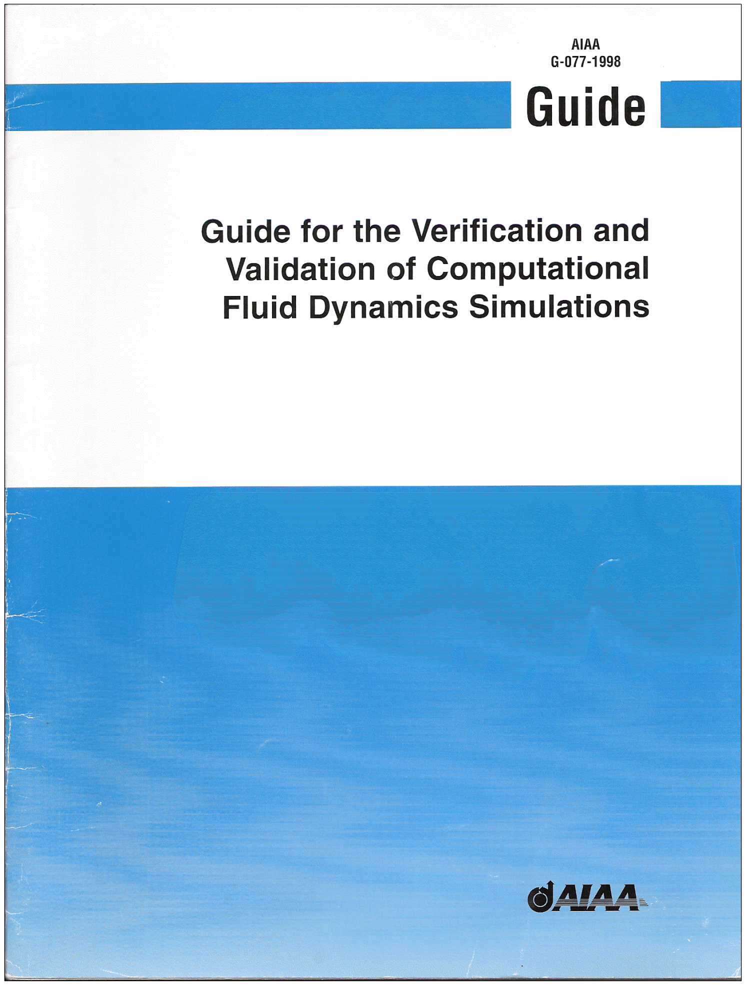
Hugh Coleman, UAHuntsville, Chair
Chris Freitas, SwRI, Vice-Chair
Glenn Steele, Miss. State Univ.
Patrick Roache, Consultant
Urmila Ghia, Univ. Cincinnati
Ben Blackwell, Consultant (retired Sandia-ABQ)
Kevin Dowding (Sandia-ABQ)
Richard Hills, New Mexico State Univ.
Roger Logan, Lawrence Livermore Nat'l Lab.

How Does V&V 20 Fit With Previously-Published V&V Guides ?

•AIAA CFD Standards Committee: AIAA Guide G-077-1998 “Guide for the Verification and Validation of Computational Fluid Dynamics Simulations”

•ASME PTC 60: V&V 10 (2006) “Guide for Verification and Validation in Computational Solid Mechanics”

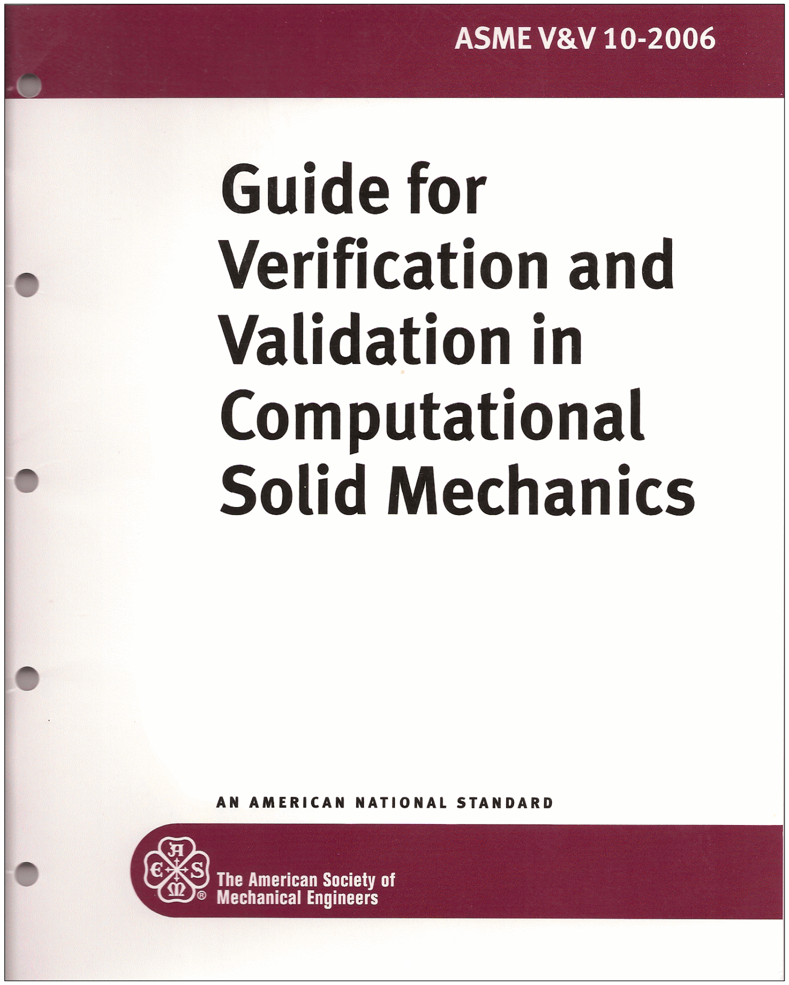
•ASME PTC 61: V&V 20 (2008) “Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer”



- AIAA CFD Standards Committee: AIAA Guide G-077-1998 “Guide for the Verification and Validation of Computational Fluid Dynamics Simulations”

  – Error: A recognizable deficiency in any phase or activity of modeling and simulation that is not due to lack of knowledge.

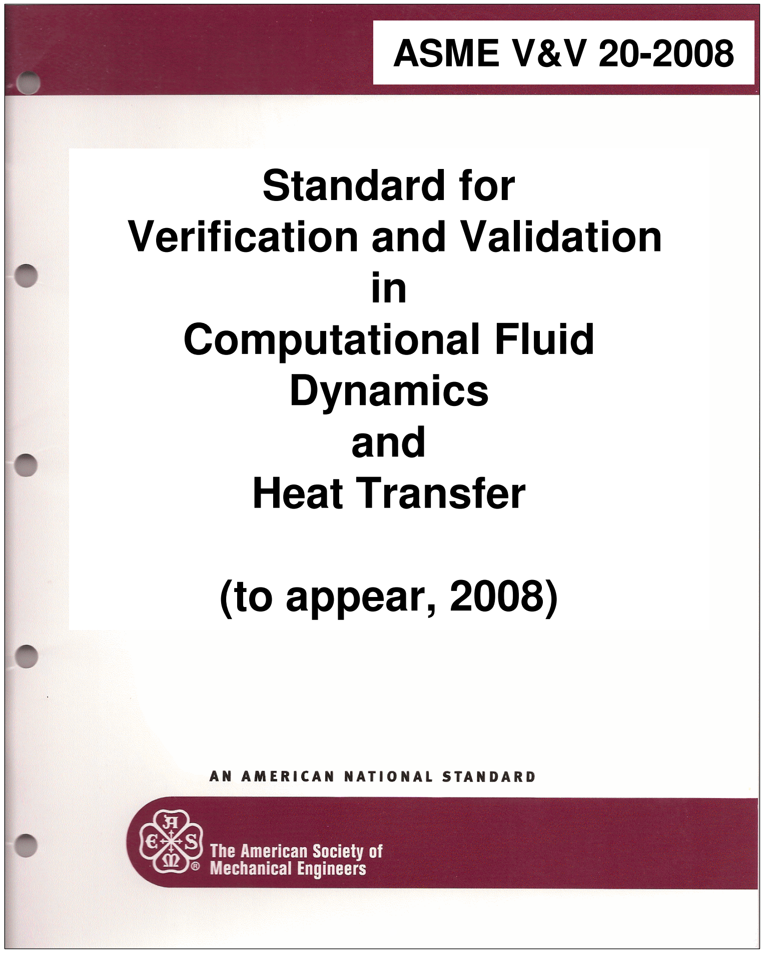
  – Uncertainty: A potential deficiency in any phase or activity of the modeling process that is due to lack of knowledge.



•ASME PTC 60: <u>V&V 10 (2006)</u> "Guide for Verification and Validation in Computational Solid Mechanics"

– <u>Error</u>: A recognizable deficiency in any phase or activity of modeling or experimentation that is not due to lack of knowledge.

– <u>Uncertainty</u>: A potential deficiency in any phase or activity of the modeling or experimentation process that is due to inherent variability or lack of knowledge.



- The objective of V&V 20:

  the specification of an 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 V&V 20:

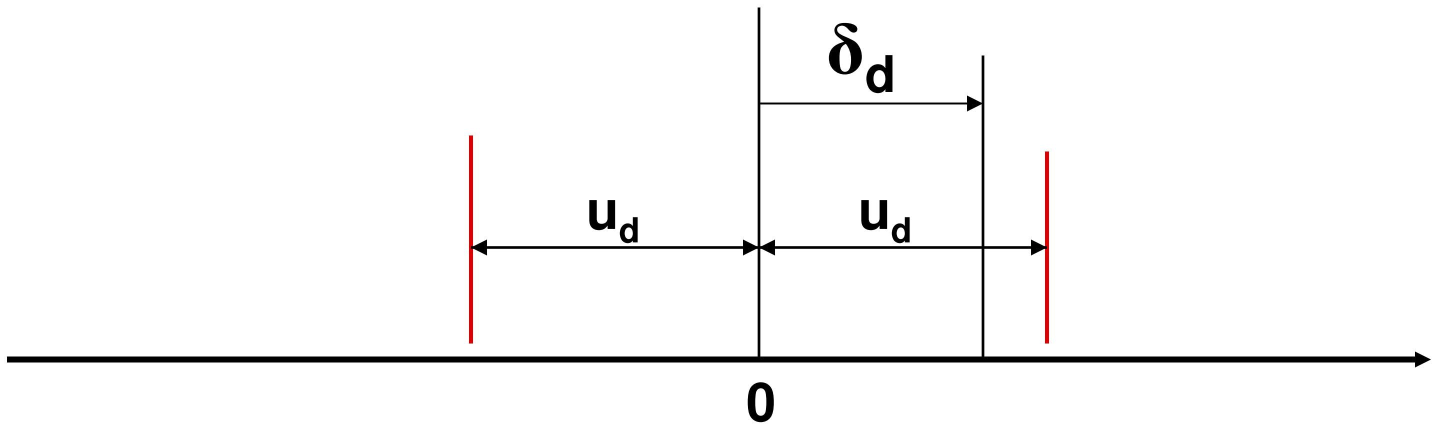
  the quantification of the degree of accuracy for cases in which the conditions of the actual experiment are simulated.

"How good is the prediction? What is the modeling error?" --- at the validation point --- when the experiment itself is simulated.

Experimental Uncertainty Concepts: Error and Uncertainty

An error δ is a quantity with a sign and magnitude. A specific error δ_i is the difference (caused by error source *i*) between a quantity (measured or simulated) and its true value. (We assume there has been a correction made for any error whose sign and magnitude is known, so the errors that remain are of unknown sign and magnitude.)

An uncertainty u_i is an estimate of an interval $\pm u_i$ that should contain δ_i.
(A standard uncertainty u is an estimate of the standard deviation of the parent distribution of δ: ISO GUM)



For example, for an (unknown) error δ_d in the data, u_d would be the standard uncertainty estimate.

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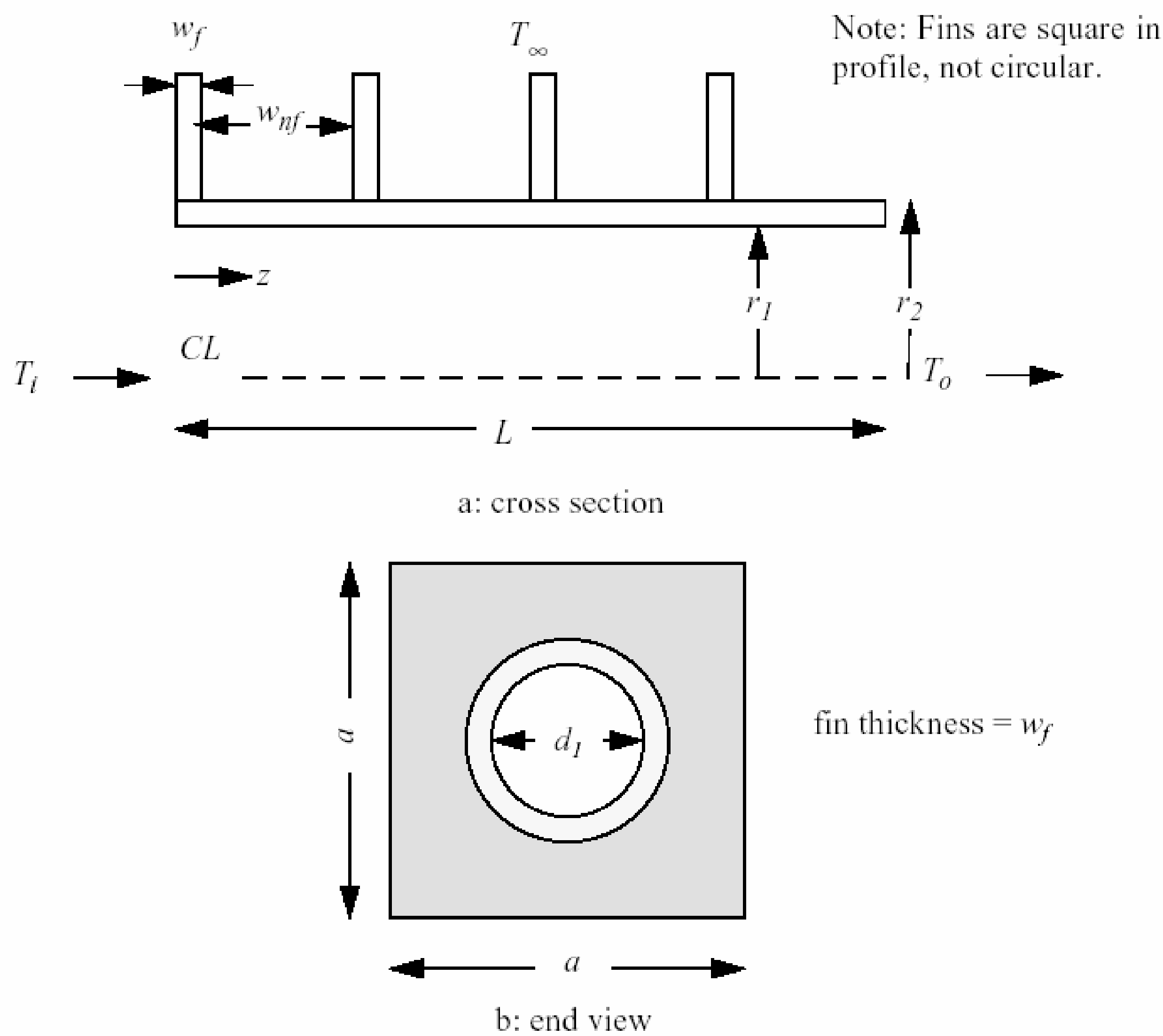
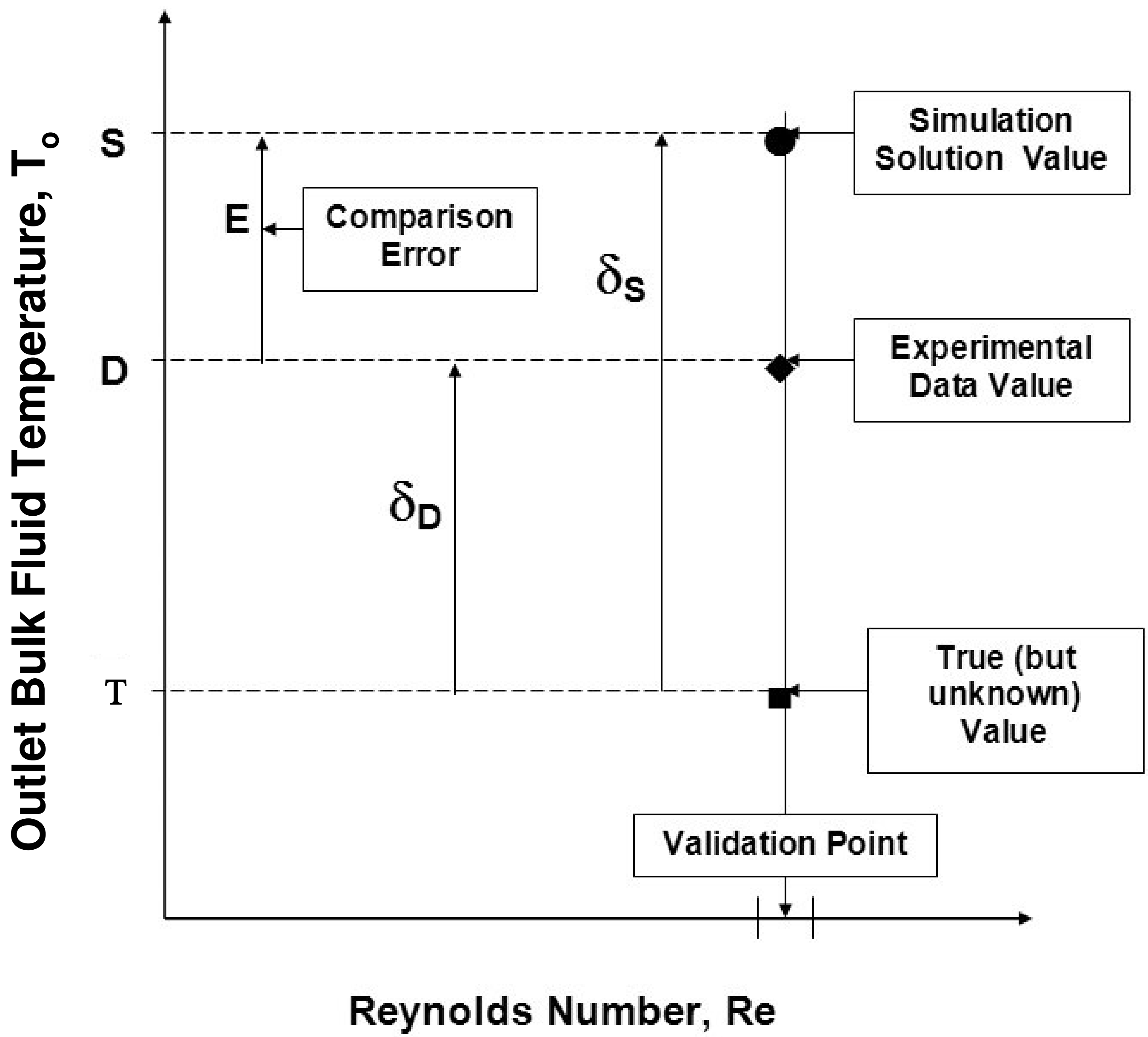
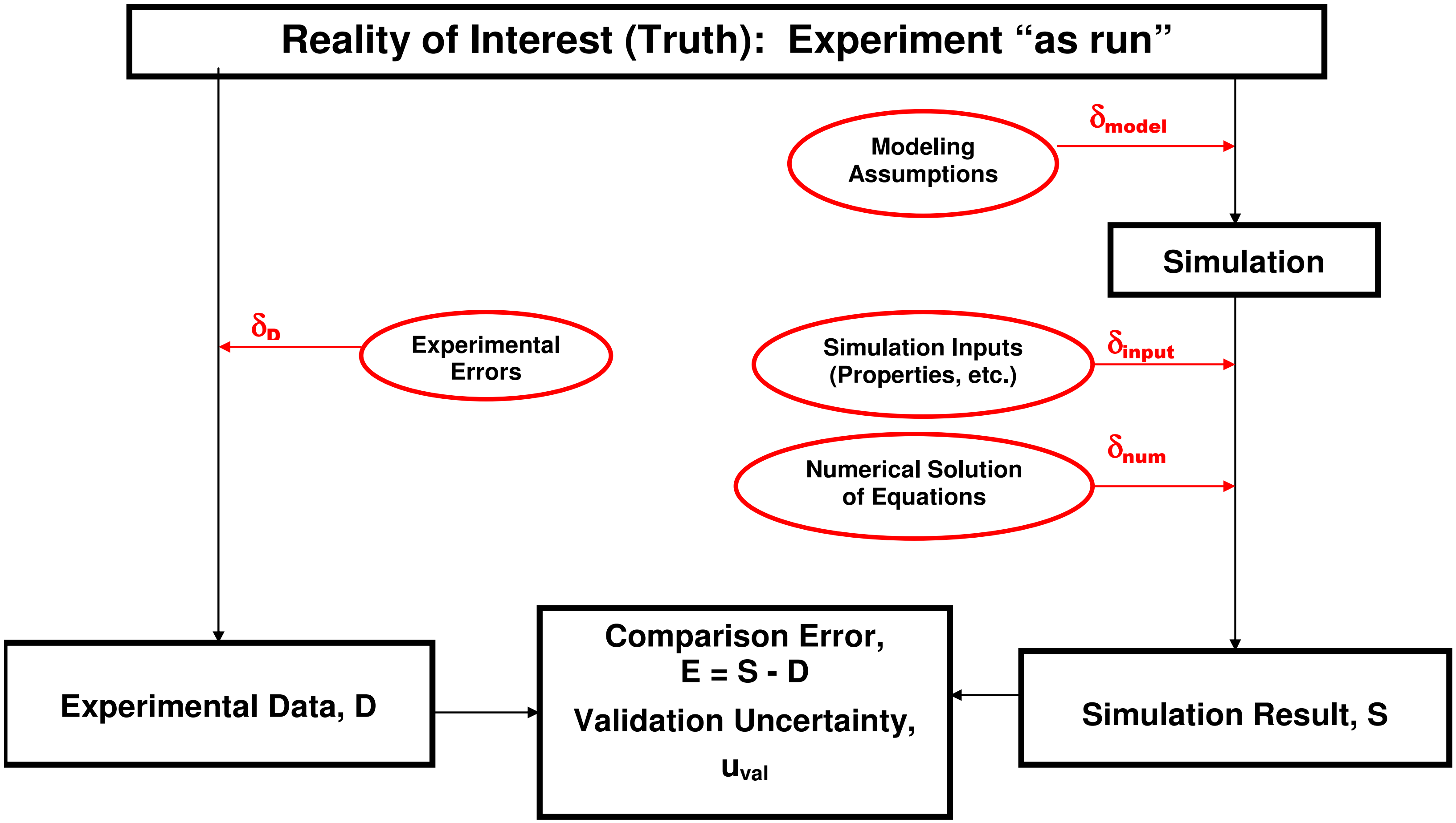
Example for V&V 20 Nomenclature and Approach

Validation variables of interest are T_o and $q = \rho Q(T_i - T_o)$





A Validation Comparison



$$E = (\delta_{model}) + (\delta_{input} + \delta_{num} - \delta_D)$$

V&V Overview – Sources of Error Shown in Ovals

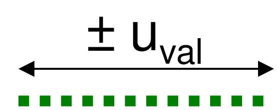
Strategy of the Approach

• Isolate the modeling error, having a value or uncertainty for everything else

$$E = \delta_{model} + (\delta_{input} + \delta_{num} - \delta_D) \longrightarrow$$

$$\delta_{model} = E - (\delta_{input} + \delta_{num} - \delta_D)$$

• If $\pm u_{val}$ is an interval that includes $(\delta_{input} + \delta_{num} - \delta_D) \longrightarrow$



then δ_{model} lies within the interval

$$E \pm u_{val}$$

Uncertainty Estimates Necessary to Obtain the Validation Uncertainty u_{val}

$$u_{val} = \left(u_D^2 + u_{num}^2 + u_{input}^2 \right)^{1/2}$$

- Uncertainty in simulation result due to numerical solution of the equations, u_{num} (code and solution verification)

- Uncertainty in experimental result, u_D

- Uncertainty in simulation result due to uncertainties in code inputs, u_{input}

Propagation by
(A) Taylor Series
(B) Monte Carlo

Uncertainty Estimates Necessary to Obtain the Validation Uncertainty u_{val}

$$u_{val} = \left(u_D^2 + u_{num}^2 + u_{input}^2\right)^{1/2}$$

- Code verification: establishes that the code accurately solves the conceptual model incorporated in the code, i.e. that the code is free of mistakes for the simulations of interest. (MMS, ….)

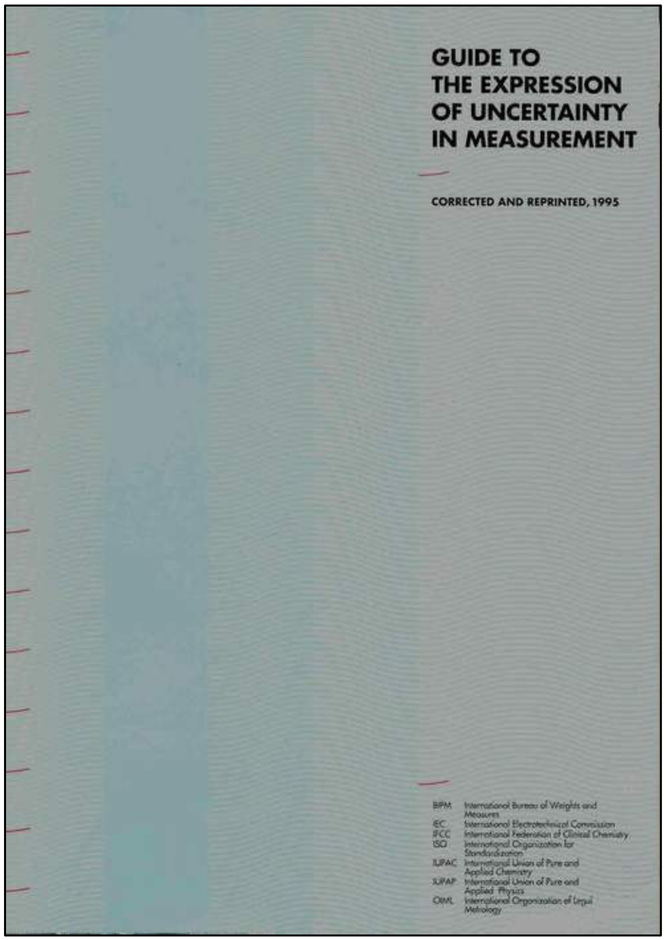
- Solution verification: estimates the numerical accuracy of a particular calculation, i.e., u_{num}. (RE, GCI, ….)

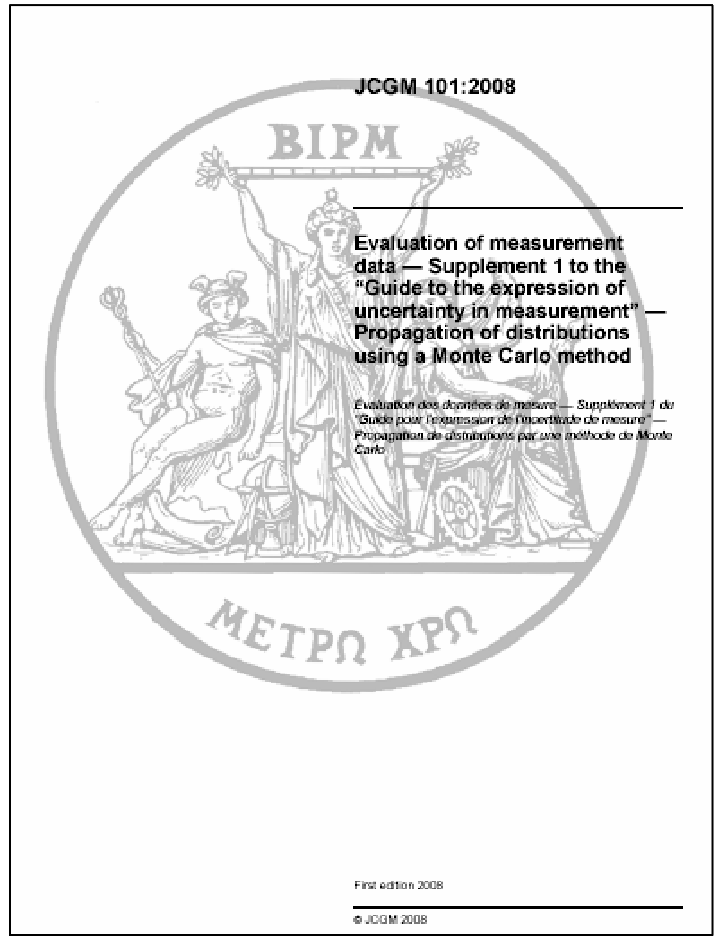
- Eça, L., Hoekstra, M., and Roache, P. J. (2007), "Verification of Calculations: an Overview of the Second Lisbon Workshop," AIAA Paper 2007-4089.

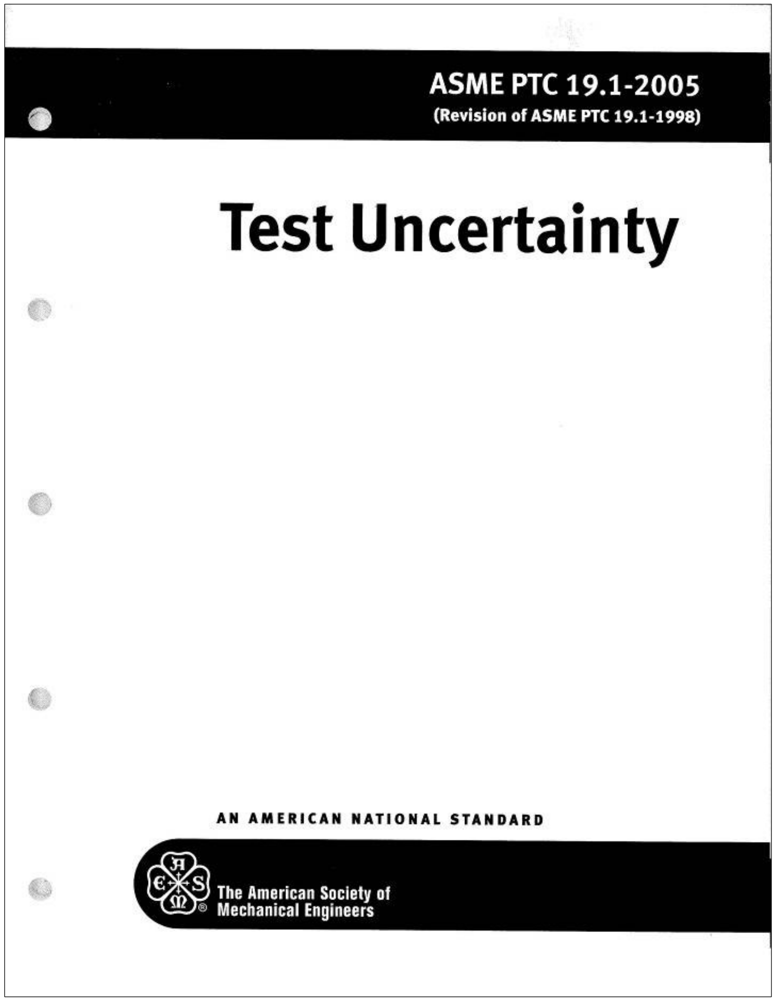
Uncertainty Estimates Necessary to Obtain the Validation Uncertainty u_{val}

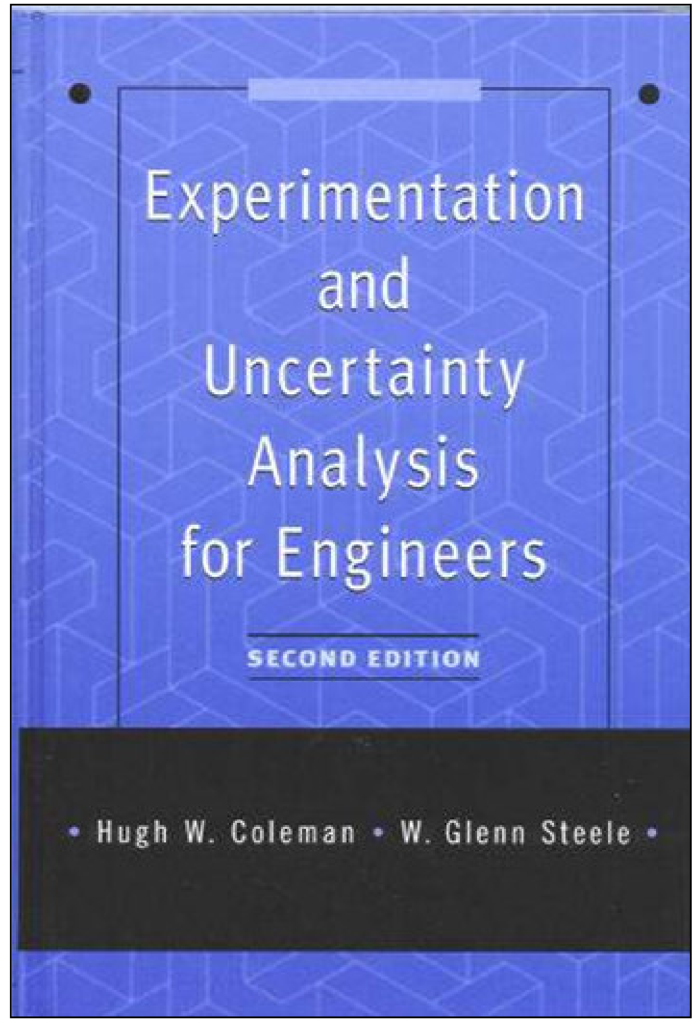
$$u_{val} = \left(u_D^2 + u_{num}^2 + u_{input}^2 \right)^{1/2}$$

- u_D can be estimated using experimental uncertainty analysis techniques









3rd Edition in 2009

Uncertainty Estimates Necessary to Obtain the Validation Uncertainty u_{val}

$$u_{val} = \left(u_D^2 + u_{num}^2 + u_{input}^2 \right)^{1/2}$$

Taylor Series propagation approach to estimating u_{input}

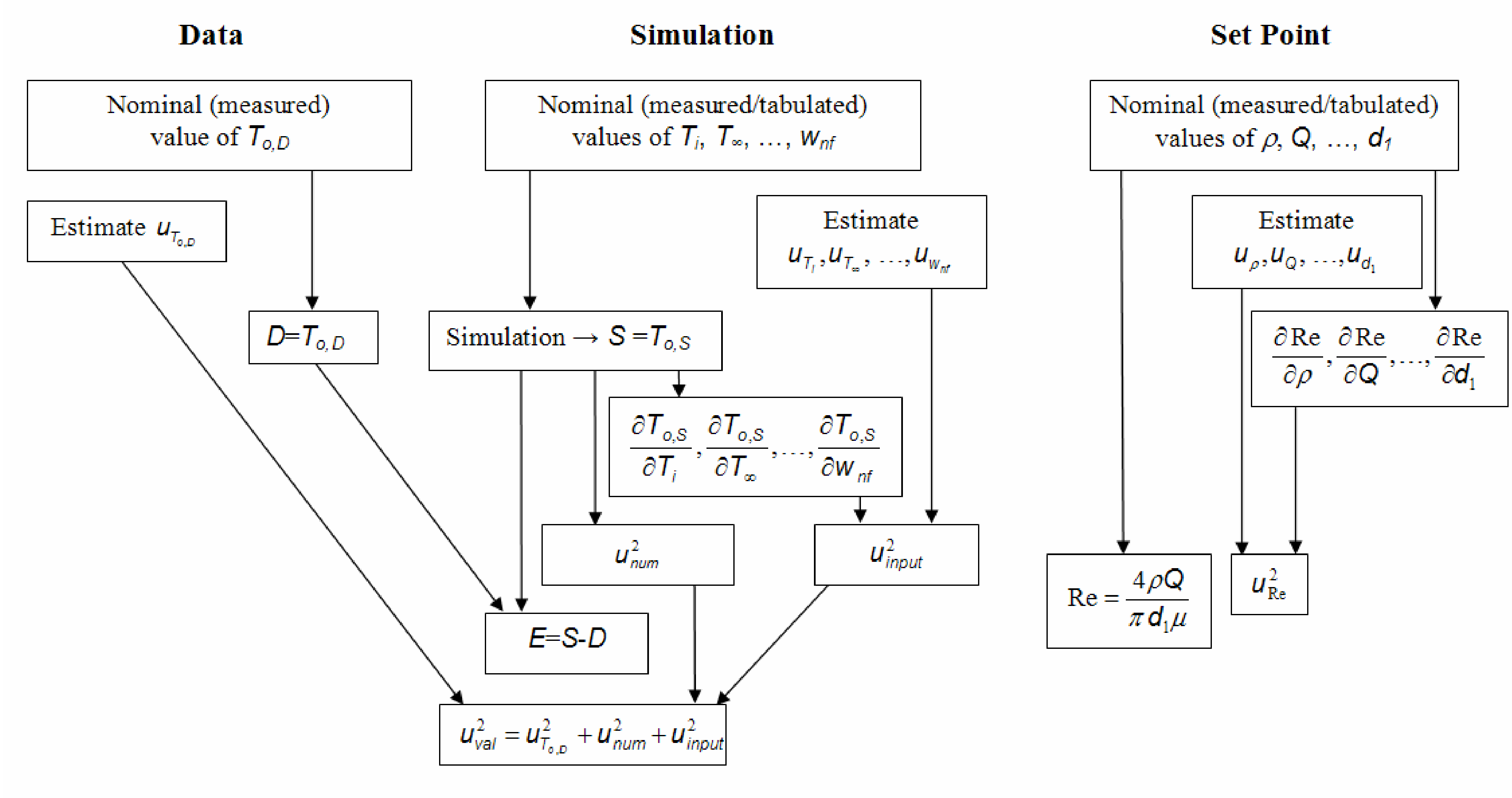
$$\mathbf{u_{input}^2} = \sum_{i=1}^{m} \left(\frac{\partial \mathbf{S}}{\partial \mathbf{X_i}} \right)^2 \left(\mathbf{u_{X_i}} \right)^2$$

and the u_{X_i} are the uncertainties in the m simulation inputs X_i

(This expression for u_{input} is strictly true only when there are no shared variables in S and D. A more complex form is necessary if S and D contain shared variables, and is presented in detail in V&V 20)

Taylor Series approach for estimating u_{val} when the validation variable T_o is directly-measured ($T_{o,D}$) and predicted with the simulation ($T_{o,S}$) as

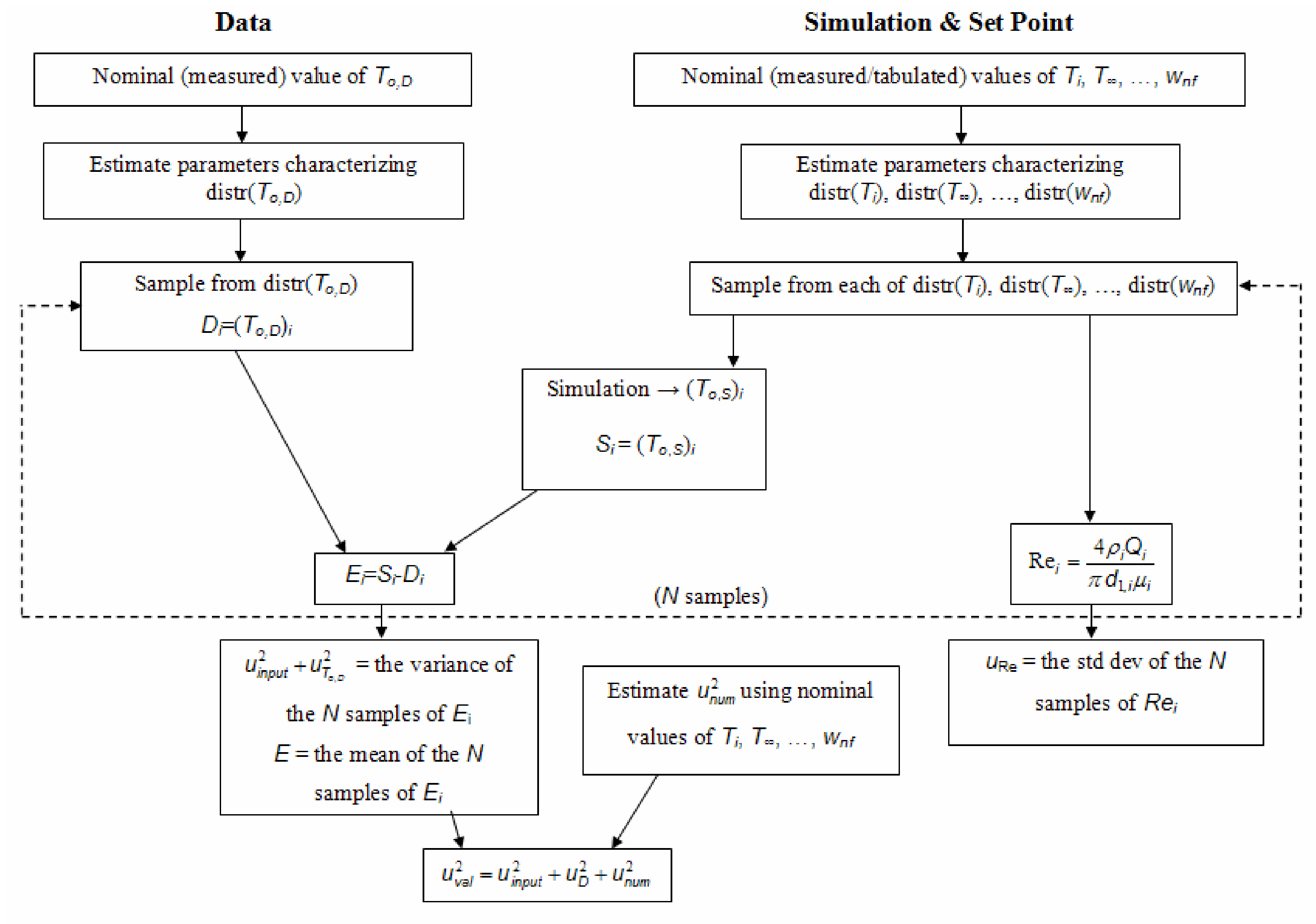
$$T_{o,S} = T_{o,S}(T_i, T_\infty, Q, \rho, \mu, C_P, h_1, h_2, h_f, h_c, k_f, k_t, d_1, d_2, L, a, w_f, w_{nf})$$



Case 1

Monte Carlo approach for estimating u_{val} when the validation variable T_o is directly-measured ($T_{o,D}$) and predicted with the simulation ($T_{o,S}$) as

$$T_{o,S} = T_{o,S}(T_i, T_\infty, Q, \rho, \mu, C_P, h_1, h_2, h_f, h_c, k_f, k_t, d_1, d_2, L, a, w_f, w_{nf})$$



Case 1

Additional Cases Covered in V&V 20

- The experimental value D of the validation variable is determined from a data reduction equation

$$q_D = \rho Q C_P \left(T_{i,D} - T_{o,D} \right)$$

and the simulation value predicted as

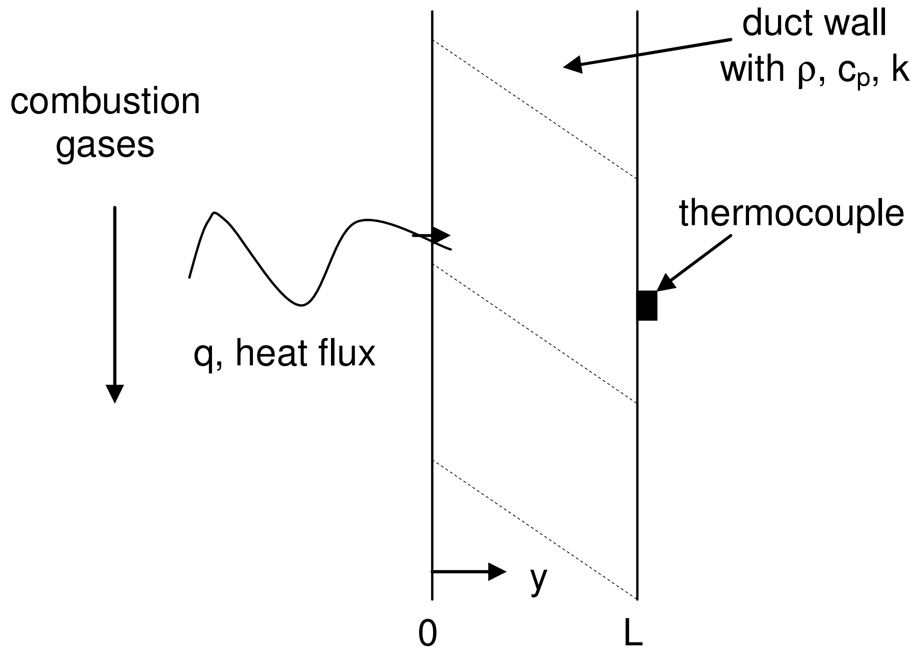
$$q_S = \rho Q C_P \left[T_{i,D} - T_{o,S}(T_i, T_\infty, Q, \rho, \mu, C_P, h_1, h_2, h_f, h_c, k_f, k_t, d_1, d_2, L, a, w_f, w_{nf}) \right]$$

V&V 20 Case 2: $T_{i,D}$ and $T_{o,D}$ share no error sources, so there are no correlated systematic errors

V&V 20 Case 3: $T_{i,D}$ and $T_{o,D}$ are measured with transducers calibrated against the same standard, so there are correlated systematic errors

Additional Cases Covered in V&V 20

V&V 20 Case 4



Case 4 considers a combustion flow with the validation variable being duct wall heat flux q at a given location. The experimental q is inferred from temperature-time measurements at the outside combustor duct wall using a data reduction equation that is itself a model. The predicted q is from a simulation using a turbulent chemically-reacting flow code to model the flow through the duct.

Interpretation of Validation Results with No Assumptions Made about the Error Distributions

$$\delta_{model} = E - (\delta_{input} + \delta_{num} - \delta_D)$$

If $|E| >> u_{val}$

then probably $\delta_{model} \approx E$.

If $|E| \leq u_{val}$

then probably δ_{model} is of the same order as or less than $(\delta_{num} + \delta_{input} - \delta_D)$.

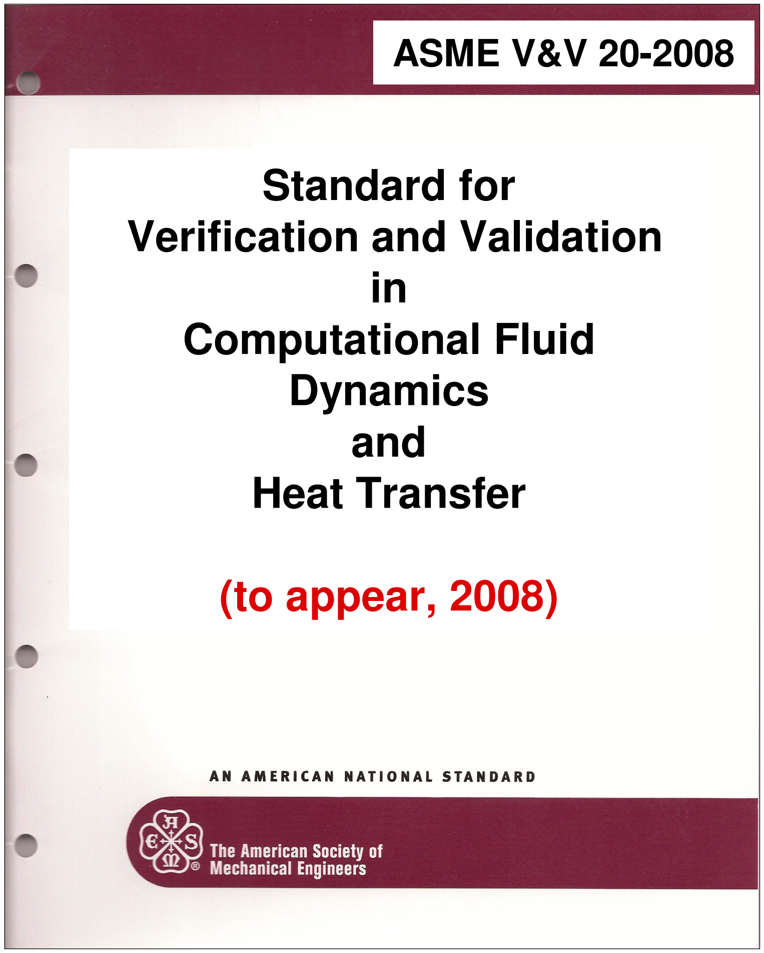
Interpretation of Validation Results with Assumptions Made about the Error Distributions

$$\delta_{model} = E - (\delta_{input} + \delta_{num} - \delta_D)$$

In order to estimate an interval within which δ_{model} falls with a given probability or degree of confidence, an assumption about the probability distribution of the error combination $(\delta_{input} + \delta_{num} - \delta_D)$ must be made. This then allows the choice of a coverage factor *k* such that

$$U_{\%} = k_{\%} u_{val}$$

One can say, for instance, that ($E \pm k_{95} u_{val}$) then defines an interval within which δ_{model} falls about 95 times out of 100 (i.e., with 95% confidence) when the coverage factor has been chosen for a level of confidence of 95%.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Questions?