

Relationships between ASME VV 10 & 20, AIAA CFD, and Real Space Model Validation Frameworks*

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* Sandia National Laboratories document SAND20- C (unlimited release)

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Context

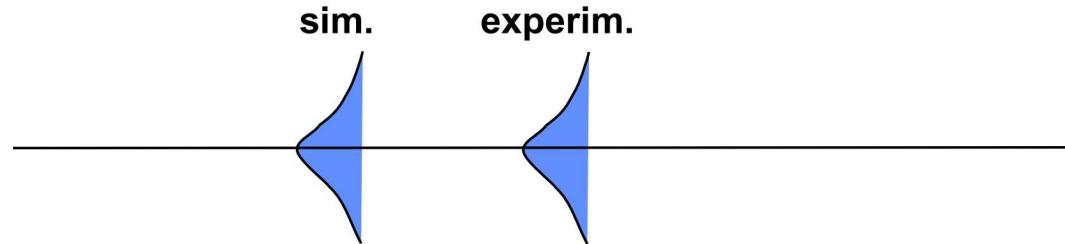


- Point out high-level structural similarities and differences between the validation frameworks
- Point out some low-level procedural approaches and details that lead to substantial quantitative differences even if similar high-level intent or paradigm for a given element or step in the methods
- Audience familiarity with the VV10 and VV20 validation approaches is assumed.

The Significance of Aleatory vs. Epistemic uncertainty in model validation



Given this uncertainty, is this model prediction perfect or likely biased?



- **Answer: it depends pivotally on the nature of the uncertainty represented by the PDFs**
 - Perfect model if the PDFs represent populations of results from a stochastic system tested multiple times w/ no other uncer. in the tests (aleatory uncertainty only)
 - Model likely has error if the PDFs represent only epistemic uncertainty (lack of knowledge) regarding the deterministic value of a response

Treatment of Aleatory and Epistemic Uncertainties in model validation frameworks



- **ASME V&V20 Standard for V&V in CFD and Heat Transfer**
 - emphasis on epistemic uncertainty and deterministic systems
 - scalar QOIs, S – D subtractive metric, probabilistic uncer.
 - some applicability to stochastic systems: **Eca et al. 2020 V&V Symp.**
- **ASME V&V10 for Solid Mech., AIAA CFD (2016 Lee et al. AIAA pap.)**
 - emphasis on aleatory uncertainty and stochastic systems
 - scalar QOIs, Area metric difference measure for aleatory CDFs
 - probabilistic aleatory and interval epistemic uncertainties
- **Real Space**
 - fully spans both epistemic and aleatory uncertainties, deterministic or stochastic systems
 - scalar QOIs, no metric (“real space” comparisons)
 - interval and/or probabilistic uncertainties of deterministic or statistical QOIs + traveling models & uncertainties + sparse-data treatment

The following updates a talk from 5 years ago



The Real-Space Model Validation Approach as a Unifying? Extended Hybrid of the ASME VV10 and VV20 Approaches[†]

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Structural Equivalence between ASME VV20 and Real-Space

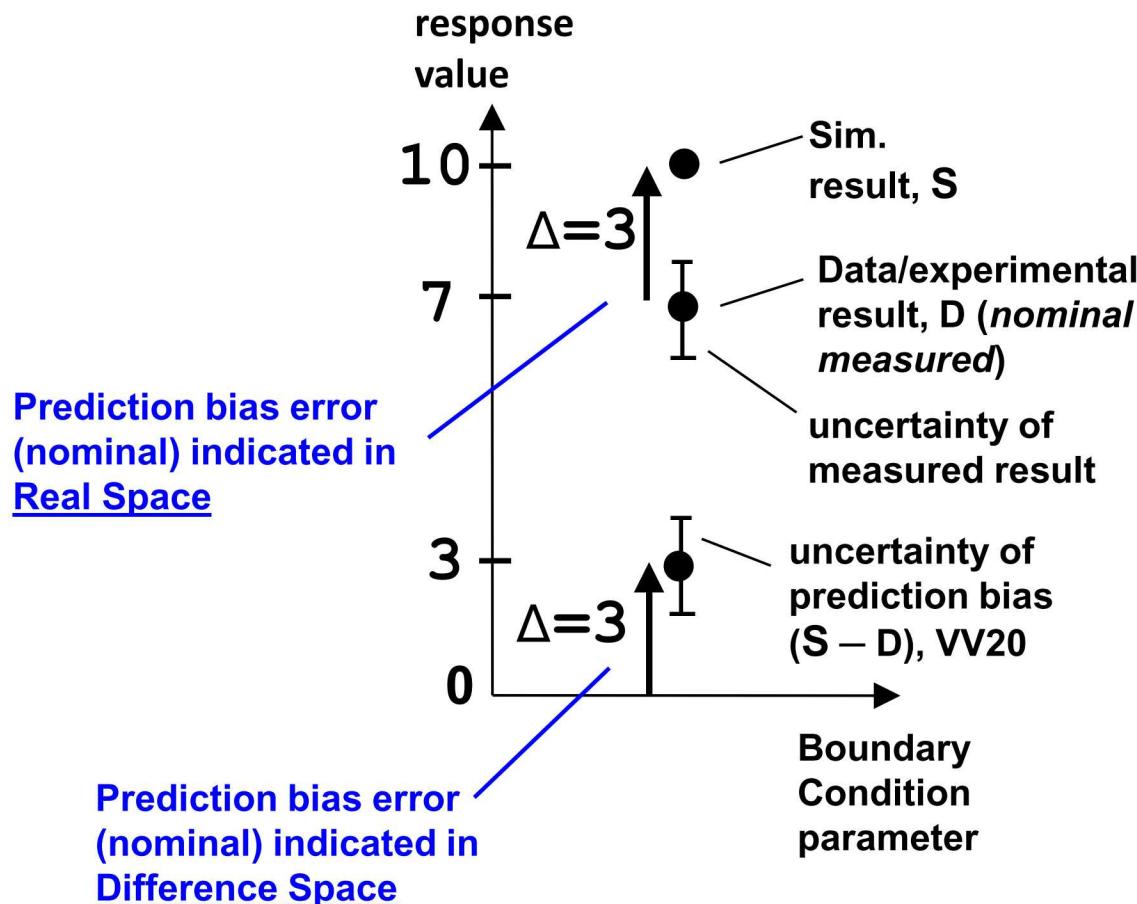
for special case:

- 1 validation test (epistemic uncertainty only, no test-to-test aleatory variation of errors or associated uncertainty)
- Probabilistic uncertainty descriptions
- No “traveling” uncertainties (defined later)

(next 3 slides)

Equivalence between ASME VV20 and Real-Space for 1 test and epistemic non-traveling uncertainties

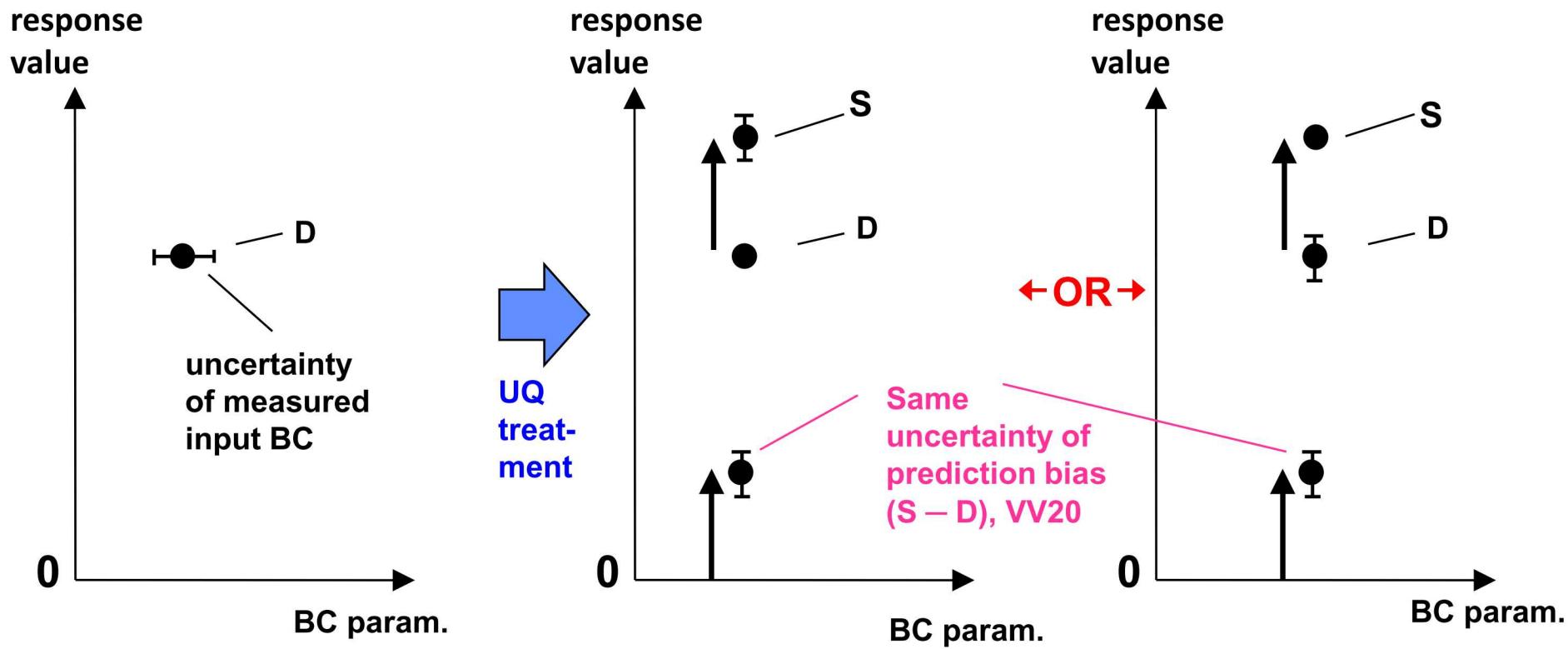
- Start with uncertainty in measurement of output quantity



Equivalence between ASME VV20 and Real-Space for 1 test and epistemic non-traveling uncertainties

- Uncertainty in measured input but no uncertainty in measured output

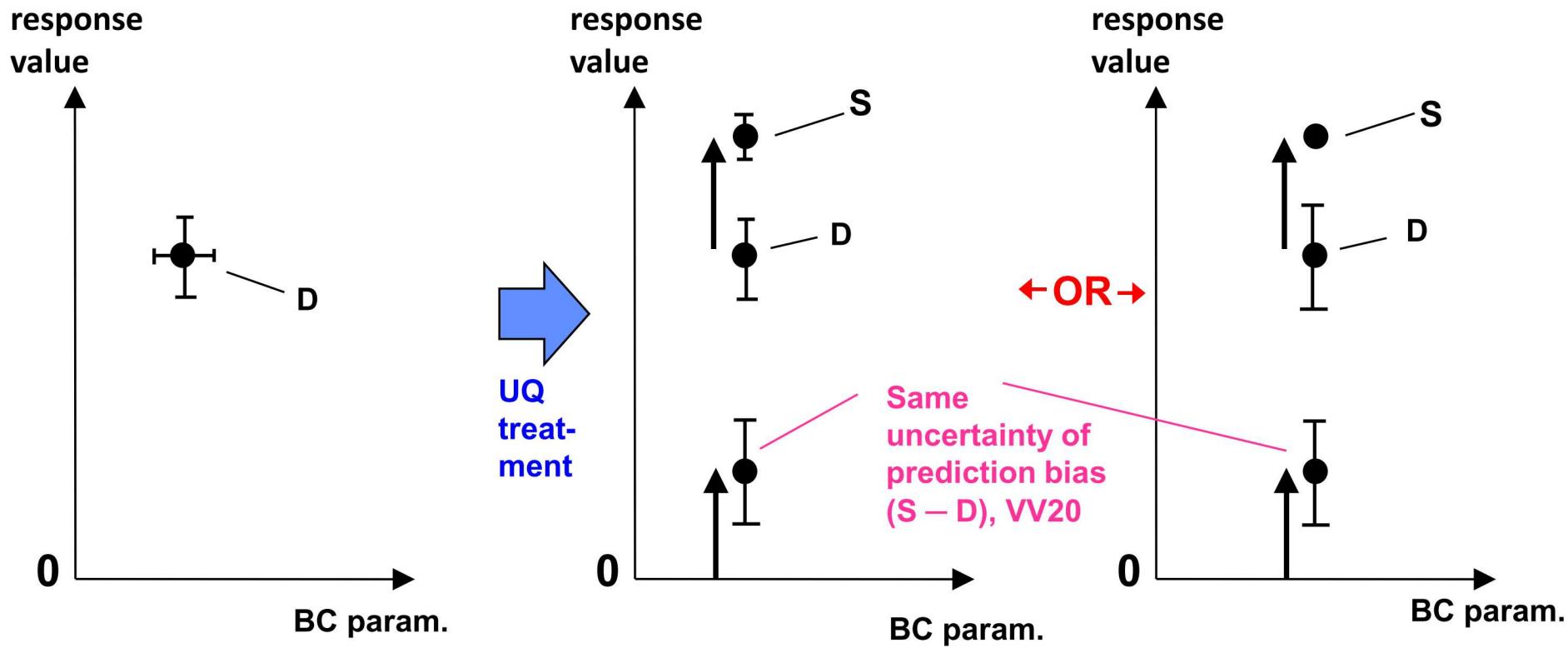
Real Space choice



Equivalence between ASME VV20 and Real-Space for 1 test and epistemic non-traveling uncertainties

- Uncertainty in measured experimental input and output

Real Space choice



Concept of “Traveling” and “Non-Traveling” Uncertainties



Traveling Uncertainties are intrinsic to the model being validated

They come with the model as a consequence of model-form error and/or lack of knowledge about values of parameters in the model.

They are consistent between the validation conditions and model applications beyond the validation activity.

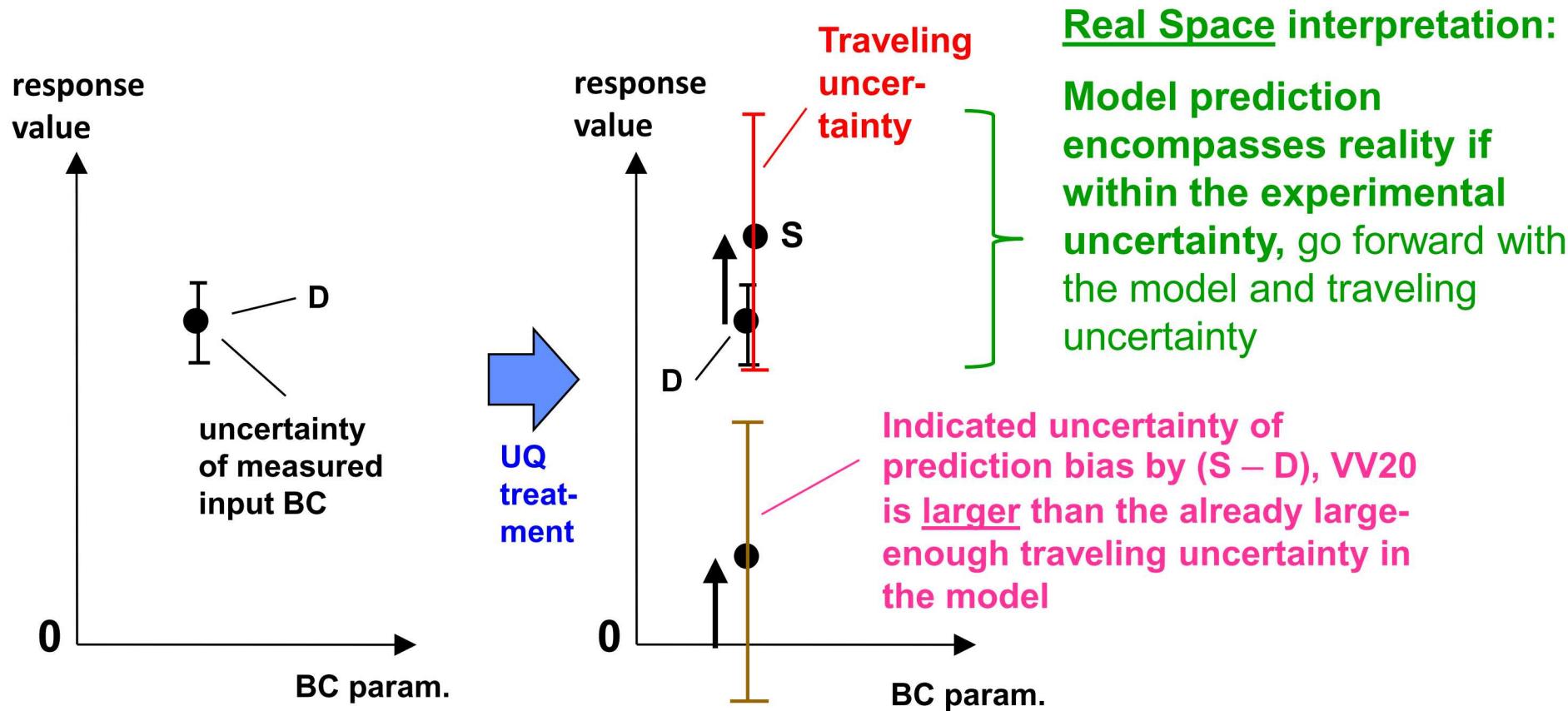
Non-Traveling uncertainties are particular to the validation activity

They are outside the traveling model of extrapolation interest

Handling Traveling Epistemic Uncertainty in Model

Non-Equivalence between ASME VV20 and Real-Space

- Model-intrinsic traveling uncertainty and uncertainty in measured experimental output



ASME VV10 and AIAA CFD approaches (One Experiment)



- Depending on the details, ASME VV10 and AIAA CFD does in some cases properly account for traveling epistemic uncertainties in the model
- But do not show how to handle complex experimental uncertainty:
 - random and systematic components of error and correlated errors in measurements of inputs and outputs
- ASME VV20 has demonstrated complex experimental uncertainty with probabilistic uncertainties
- Real Space has demonstrated complex experimental uncertainty with probabilistic and/or interval uncertainties

Multiple Replicate Tests with Stochastically Varying Systems

- For validation of models with traveling aleatory uncertainty that represents the stochastic variability in the systems
- random/aleatory variation of the systems from test-to-test
- test-to-test random/aleatory variation of measurement errors on inputs and/or outputs; associated “random” uncertainties
- test-to-test systematic (constant) errors in measurements of inputs and/or outputs; associated “systematic” uncertainties

Treatment of Experimental Uncertainties in Multiple Replicate Tests



- **ASME VV10 and AIAA CFD approaches**
 - complex experimental uncertainties on the output data samples and input conditions have not been shown how to be treated
- **ASME VV20**
 - treatment of complex experimental uncertainties is applied for probabilistic uncertainties
- **Real Space**
 - treatment of complex experimental uncertainties is applied for probabilistic and/or interval uncertainties
 - Normalization to subtract-out variability in output data samples due to test-to-test differences of experimental inputs is also part of the RS method (**my talk earlier today**) – avoids exaggeration of response variability and yields better IID basis for statistics

Sparse Experimental Sample Data:

Treatment of associated Epistemic Uncertainty in CDFs or Statistics

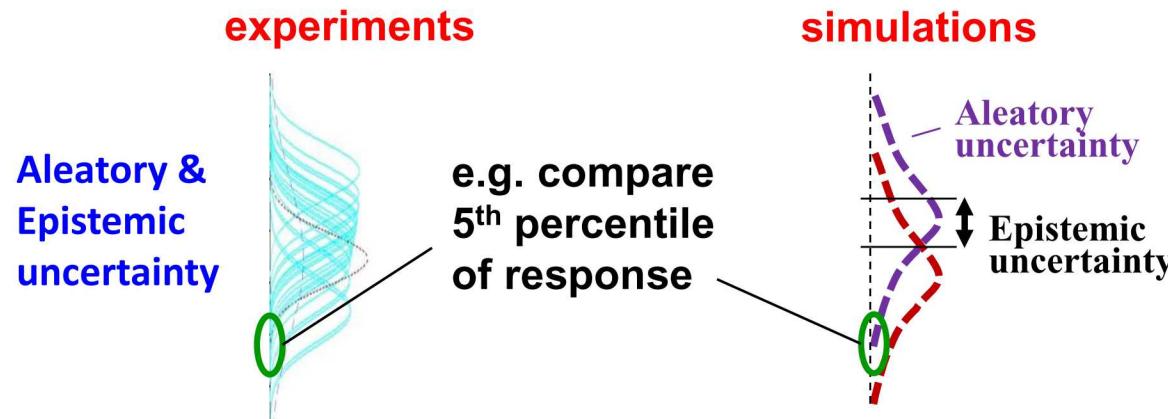


- Epistemic uncertainty is huge for realistically sparse sample data in most physical engineering situations:
 - Example
 - A 95% coverage interval estimated from a Normal fit to 8 samples drawn from a Normal distribution has an empirical confidence of about 26% for capturing the true central 95%, 32 samples → 28% confidence
- ASME VV10 and AIAA CFD approaches
 - no demonstrated adequate treatment
- ASME VV20
 - no demonstrated adequate treatment
- Real Space
 - substantial theoretical and empirical basis for statistical treatments

Real Space comparison for Stochastic Experimental and Simulation Results



- Compare decision-intuitive statistical measures of response, not CDFs



- Intuitive visual indication of how accurate the model is, on several fronts:
 - Means of the predicted and experimental populations
 - Variances
 - Percentiles
 - Range of response %age, e.g. the “central” 95% between 2.5 and 97.5 percentiles
(These last two account for combined uncertainty in mean, variance, and possible higher moments of stochastic response and are found to be the most useful in practice)
- Percentile comparisons are particularly useful for validation of models to be used for analysis of performance and safety margins, e.g. QMU.

ASME VV20 validation approach for Stochastic Experimental and Simulation Results



- Today's talk by Eca et al. indicated a subtractive difference metric and uncertainty applied to predicted and experimental 1-parameter statistics of response:
 - **Means** of the predicted and experimental populations
 - **Variances**
 - **Percentiles**
 - **Not 2-parameter statistical quantities** like prediction intervals, central 95% range of response, etc.
- The $u_{\text{val}} = [(u_{\text{input}})^2 + (u_D)^2 + (u_{\text{num}})^2]^{1/2}$ formulation for uncertainty of the bias between the experimental and predicted statistics may not give reliable results given the nature of estimation uncertainties (e.g. one-sided bounds for percentiles) when sparse data are involved

ASME VV10 and AIAA CDF validation approach for Stochastic Experimental and Simulation Results



- Area metric gives a measure of disagreement of experimental and simulated CDFs
- Somewhat difficult to interpret what it means for two CDFs to be different by x.y in any metric, including the Area metric
- Non-uniqueness: any number of CDF mismatches can yield the same metric value x.y
- The two CDFs being compared will in general both be uncertain, so represented by Probability Boxes; the metric value becomes an uncertain quantity. How best handle?
- Interpretability may hamper decision making regarding model adequacy and correction of prediction bias and extrapolation of the correction to new predictions

Prediction Bias Correction and Extrapolation



- **ASME VV10 and AIAA CFD approaches**
 - Bias correction according to Area metric can only be exact for at most a single percentile of the CDF and will not be accurate for other percentiles, same for extrapolation
- **ASME VV20**
 - no established bias-correction or extrapolation methodology
- **Real Space**
 - Prediction bias correction for a selected percentile of response and Predictor-Corrector extrapolation of the correction, with extrapolation uncertainty scaled to extrapolation distance
(V&V Symposium talk last year)

Closing Remarks



- **Model validation is complex -- philosophically, conceptually, and procedurally**
- **Many different conceptions, approaches, and frameworks exist and the area is still rapidly evolving**
- **There are significant structural and procedural similarities and differences between the reviewed model validation frameworks**
- **It may be beneficial to more deeply analyze and test the various frameworks and develop a hybrid framework with the best features of each approach**