# IS THERE A PLACE FOR GENERIC MODELING UNCERTAINTY IN ENGINEERING DESIGN?

by

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# Questions Posed

- **How should we view model validation *in the context of engineering design*?**

- **How should we assess the *predictive* capability of a model in the absence of experimental data?**

- **How can we improve our confidence in predictive models for engineering design?**

- **What are the *open* critical research topics in model validation?**

- **Will we ever be able to design, develop and certify engineering systems in a pure virtual (computational) environment?**



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# Requirements for Validation of Predictive Models Used in Engineering Design

- **Model validation for engineering design will require a process compatible with and accepted by the design establishment of an organization, where:**
- **The intended use of a model is clearly specified**
- **Comparative metrics are defined**
  - Generic global metrics for uncertainty quantification – e.g. normalized modal metrics, principal components, normalized Fourier coefficients, etc.
  - Specific local metrics for validation assessment – e.g. acceleration, velocity, displacement at points of interest, time to a critical event, etc.
- **Validation assessment is performed to evaluate the comparative metrics.**
- **Acceptance criteria are defined, by which the adequacy of a model validation assessment *for the intended use of the model* is judged.**



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# Some Options for Assessing Predictive Capability in the Absence of Experimental Data

- **Use prior experience alone, based on analysis-test comparisons**
  - Accepted uses: predictive accuracy of modal frequencies for control system design
  - Suggested applications**:** predictive accuracy of complete analytical models for
    - Truss-type space structures
    - Launch vehicle payloads
    - Automobile crashworthiness simulation
- **Use a Bayesian approach with prior experience**
  - Update the covariance of model response metrics based on estimated parameter uncertainties, with a generic covariance matrix of analysis-test differences based on prior analysis and test experience.
  - Update both the mean and covariance of model response metrics based on estimated parameters and their uncertainties, with the estimated mean and covariance of analysis-test differences from prior analysis and test experience (requires more data in a narrower generic category).
- **Use a Bayesian approach with prior experience based on “lessons learned”**
  - Same as previous approach except that estimated mean and covariance from the generic database are based on analytical models that have been updated to remove identified modeling errors.
  - These modeling errors must qualify as “lessons learned” that are reflected in subsequent modeling efforts, including the current one.



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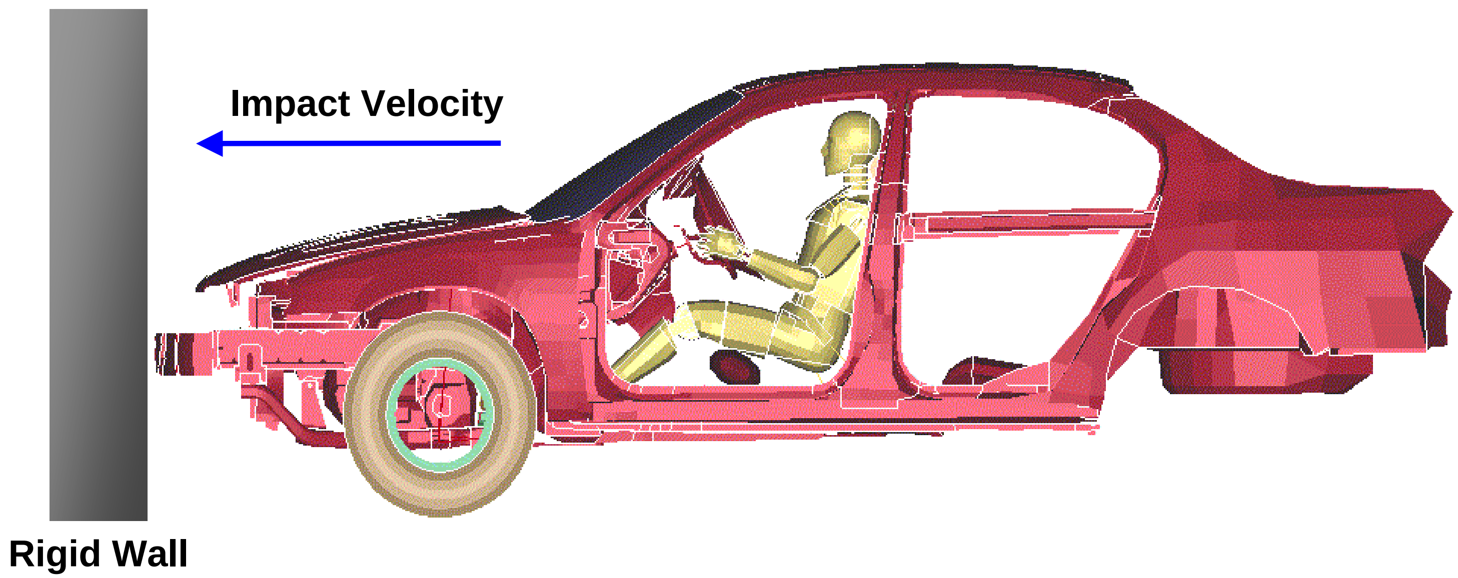
# Example: Crashworthiness Tests and Simulations (Courtesy GM)

## ❑ Crashworthiness Tests

- Midsize test vehicle
- Acceleration and force
- Measurements on vehicle, barrier, dummy
- Straight frontal, left/right angle barrier
- SDM, RadR, RadL, RadC

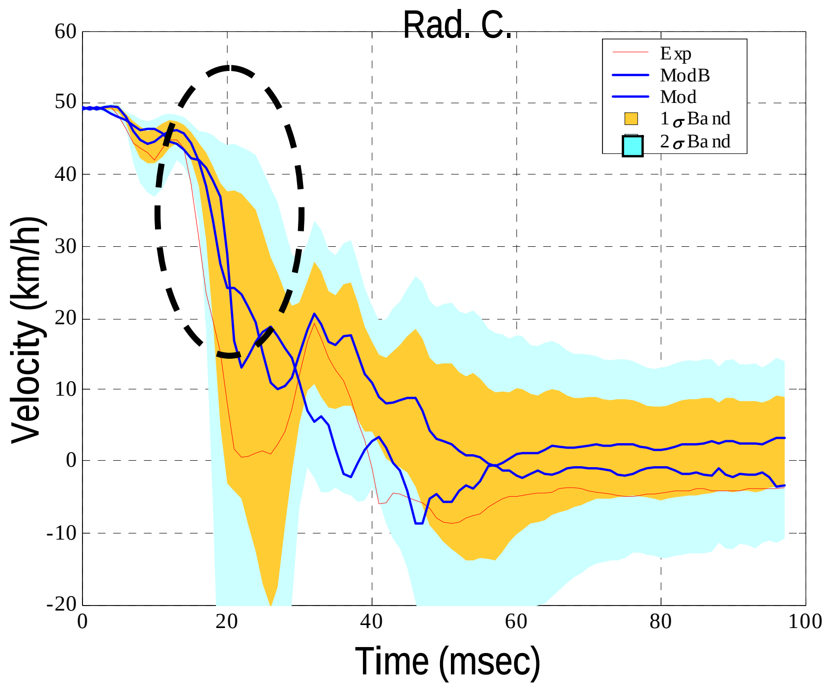
## ❑ Numerical Simulations

- LS-DYNA
- Velocity time-history
- At common locations

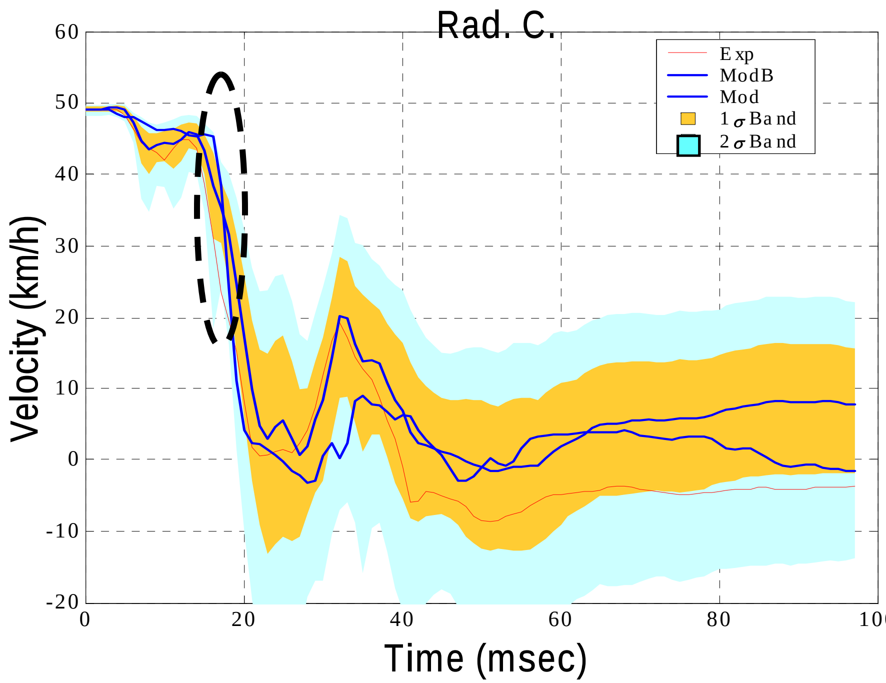


# Reduction of Modeling Uncertainty

**Prior to Model Improvement**




**After Model Improvement**




**Courtesy GM and 2005 IMAC Paper No. 278**



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# Improving Confidence in Predictive Models for Engineering Design

- Accumulate data to a generic historical database of analysis-test experience as predictive engineering design models are eventually validated by comparison with test data, i.e. build a "living" database.

- Take advantage of lessons learned in building future analytical models and compiling the historical database.

- As more data become available, attempt to narrow generic categories, thereby reducing generic modeling uncertainty.

- Update the *process* used for validating predictive models used in engineering design by periodically evaluating the performance of the process against project goals.

# Critical Research Topics

- **With regard to the use of generic modeling uncertainty in engineering design to assess the predictive accuracy of pretest models, critical research topics might include:**
  - Development of guidelines for the classification of generic categories, e.g. w.r.t. crashworthiness simulation of automobiles, one might consider size (compact, mid-size, full-size); materials (steel, aluminum, composites), model fidelity, test fidelity, etc.
  - Trade-offs between broader categories and more data sets and narrower categories with fewer data, in terms of statistical significance and sampling-based confidence levels.

- **In a broader context, one might consider in the investigation of alternative approaches:**
  - What resources are available within an organization to support various approaches, e.g. availability of required engineering data (both analysis and test data)?
  - What approach best fits the design engineering culture of an organization?
  - How long would it take to realize the benefits of a given approach?
  - Does the organization have the financial and management resources to make the necessary commitment to an engineering design validation program?

# Looking to the Future: Can we get there from here?

**Can we ever design, develop and certify engineered systems in a virtual computational environment? Some suggestions:**

- **Select an approach; outline a program with a pilot project.**
- **Demonstrate added value in the pilot project - possibly two design cycles, 2 – 5 years**
- **Estimate the short-term and long-term benefits of the program.**
- **Estimate the cost of a long-term commitment to the program.**
- **Establish goals and cost/benefit metrics so that progress toward those goals can be objectively monitored.**
- **Schedule periodic program reviews with built-in opportunities for mid-course adjustments.**



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