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Identification and Validation of Environmental Load Models Based on Structural Response

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Motivation

- Accurate assessment of system response requires
  - Accurate model of system (and its IC and BC)
  - Accurate model of excitation
- Validation assures accuracy (or adequacy) of models
  - Validation of system models is amply treated in the literature (e.g., validation of FE models)
  - Validation of excitation environments is trivial in some situations and very difficult in others – Usually ignored

Introduction

- **Model validation - "the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model"**
  - **Involves comparison of model-predicted results to experimental results to assess adequacy/accuracy of model**
  - **Adequacy/level of accuracy depends on intended model uses**
- ***We consider validation of unmeasurable environments that are nonstationary random processes***

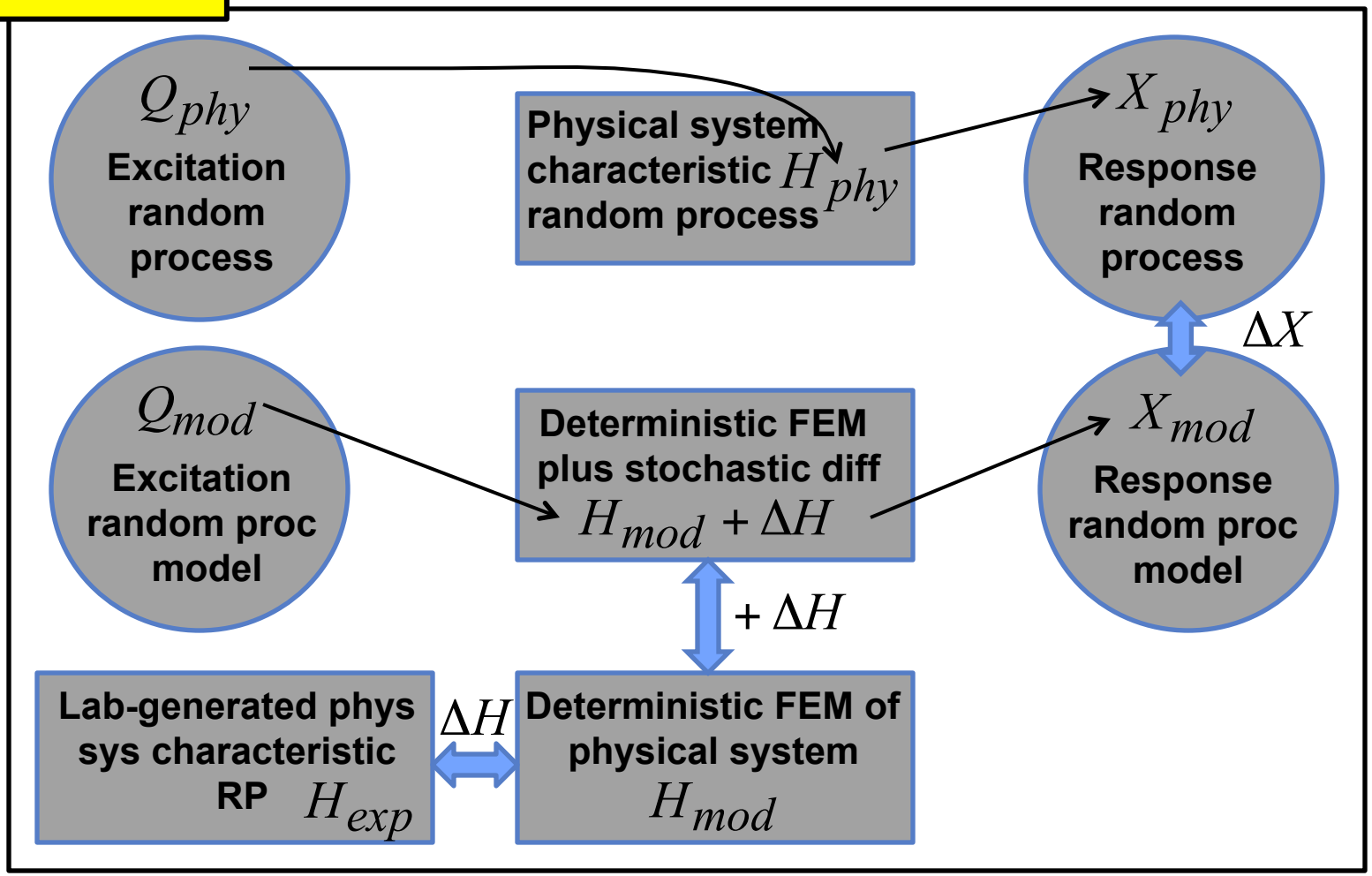
Outline

This talk will cover

- Approach to stochastic environment model validation – Ideal case
- Approach to stochastic environment model validation – Practical case
- Example – Structural dynamics during atmospheric re-entry – Validation

Environment Validation – Procedure

Ideal Case



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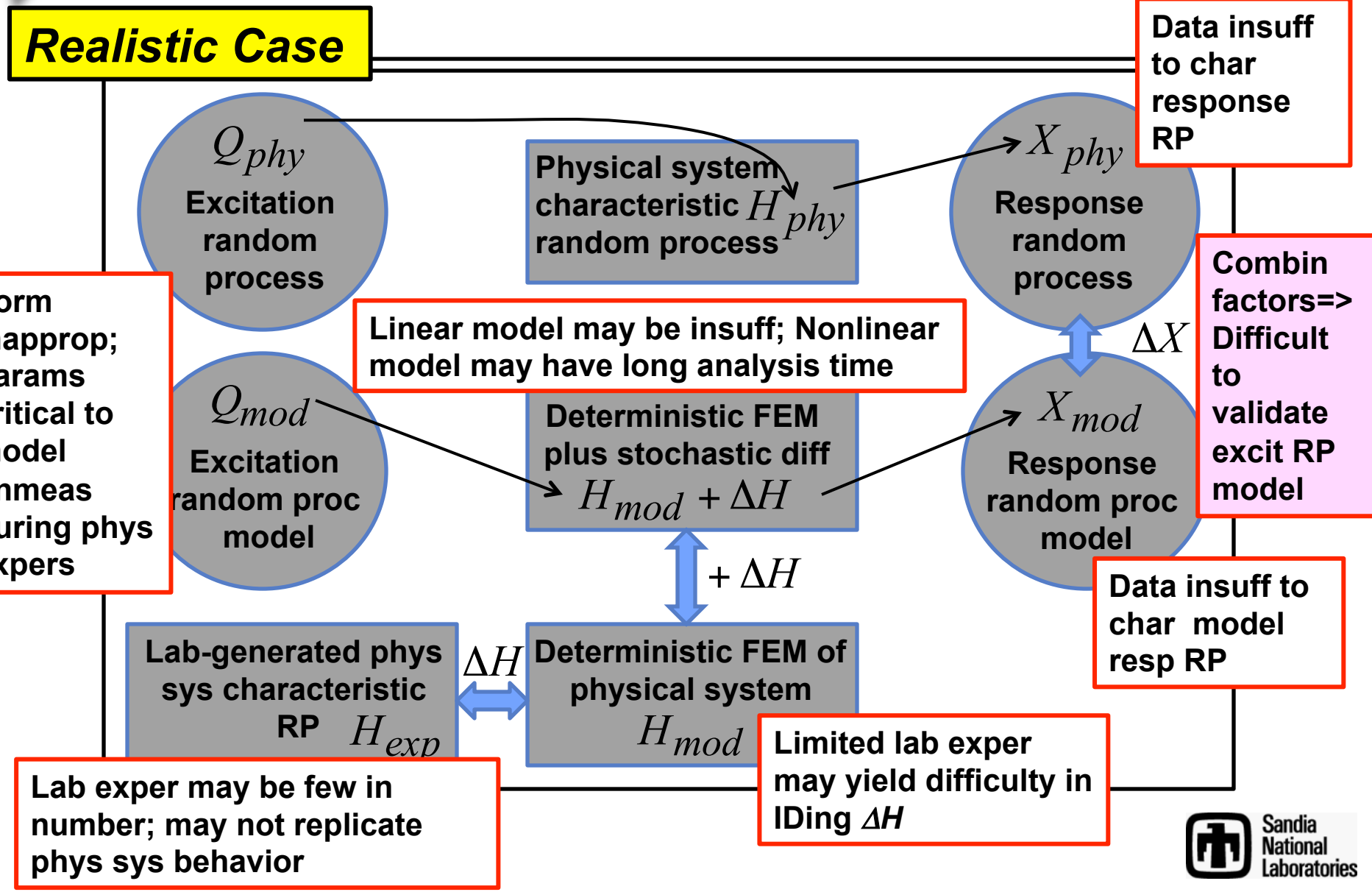
Environment Validation – Procedure



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Environment Validation

- Consider case where
  - Deterministic FEM used, alone
  - Model assumed accurate – Validated
- Measure of response – Evolutionary spectral density of nonstationary, random acceleration response process
- Priestley's model: $\{X(t), 0 \le t \le T\}$ is a nonstationary random process that may be expressed

$$X(t) = \int_{-\infty}^{\infty} A_X(\omega, t) e^{i\omega t} dZ(\omega) \qquad 0 \le t \le T$$

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Environment Validation

- **The evolutionary (time-varying) spectral density (ESD) of the response random process $\{X(t), 0 \le t \le T\}$ is**

$$S_{XX}(\omega,t) = |A_X(\omega,t)|^2 S_0(\omega) \qquad -\omega_L < \omega < \omega_L, 0 \le t \le T$$

- **When the ESD of the response computed using the model excitation is "close enough" to the ESD of the experimental response, the excitation model is validated**
- **How do we establish what is close enough?**

Environment Validation

- One validation possibility (when parameters critical in model are unmeasured during physical re-entry):
  - Generate multiple realizations of response ESD using model and spectrum of environment parameters
  - Compute ESD of available experimental re-entry responses
  - Establish whether model-generated ESDs lie (satisfactorily) within model-predicted ESDs

Environment Validation

- **Validation scheme:**
  - **At a pre-established set of times** $T_j, j = 1,\ldots,N$
  - **Estimate Karhunen-Loeve expansion of experimental response spectra**

$$G = vw^{1/2}U + \mu_G$$

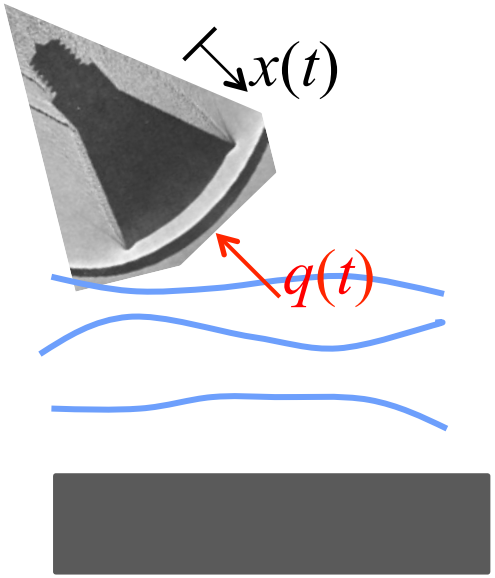
  - **Solve for underlying random variates of experimental spectra**

$$u = w^{-1/2}v^T\left(g\text{-}\mu_G\right)$$

  - **Use model-generated spectra,** g_{mod} **, in this formula, in place of** g**, to obtain** u_{mod}
  - **Use statistical test of hypothesis framework to establish whether** u_{mod} **lie among the** u

Environment Validation – Example

- Consider aerospace structure re-entering atmosphere- Loads cannot be measured
- Load model accommodates temperature layering in atmosphere



- Load is nonstationary random process – Priestley model w/ evolutionary (time-varying) spectral density
- Response modeled in same frame
- Experimental responses available, but conditions unmeasured
- Validate using ESD as specified

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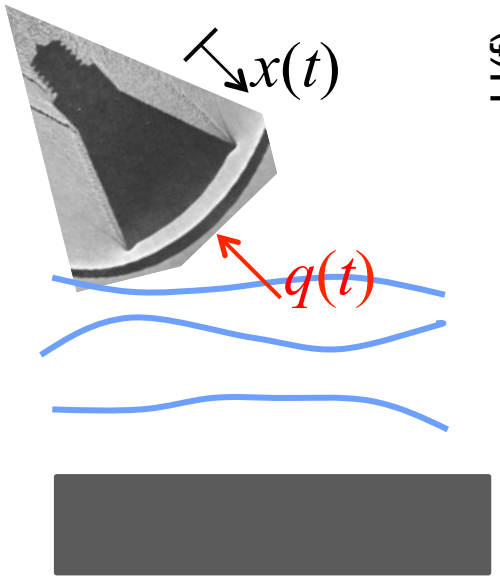
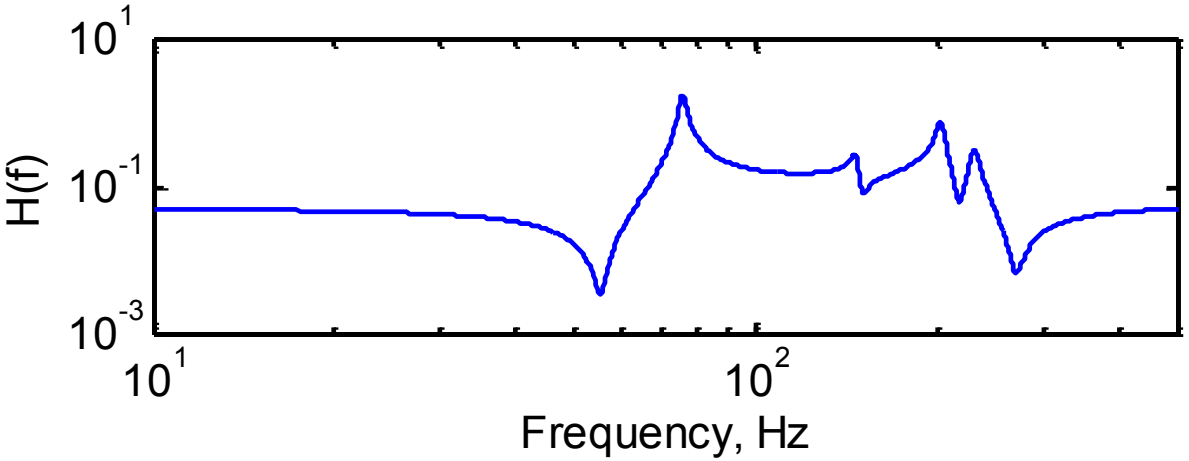
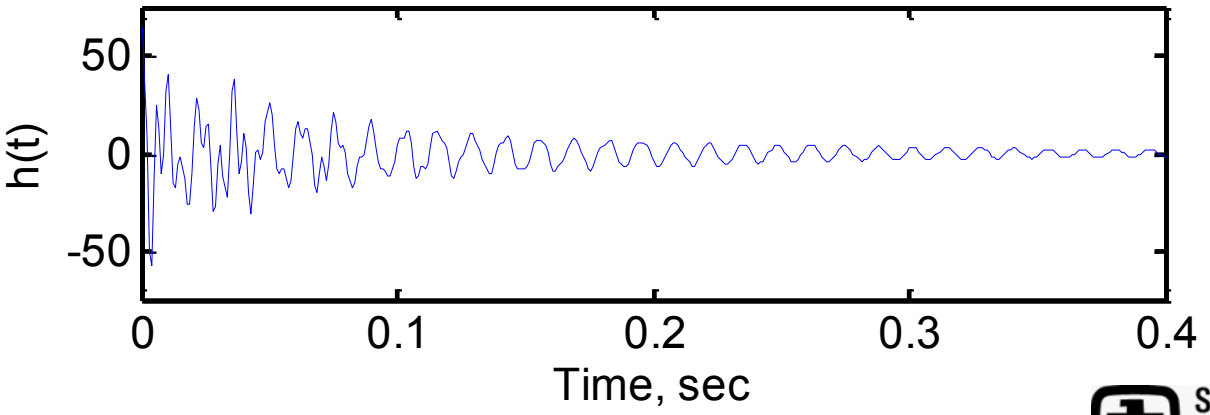
Environment Validation – Example

- **System FRF and IRF – Load is $q(t)$, response is $x(t)$**







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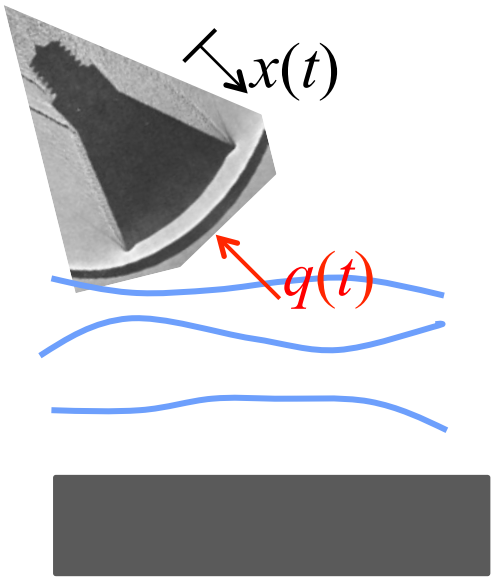
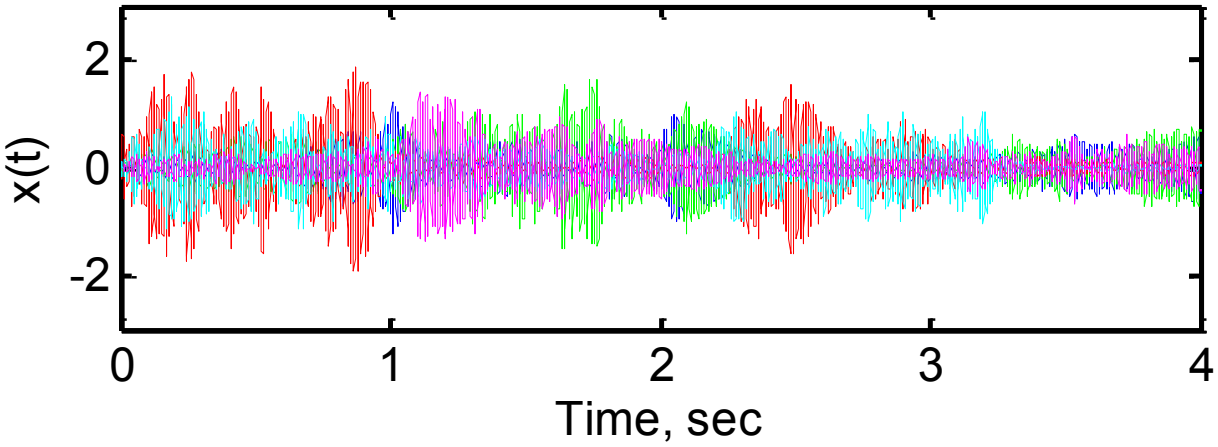
Environment Validation – Example

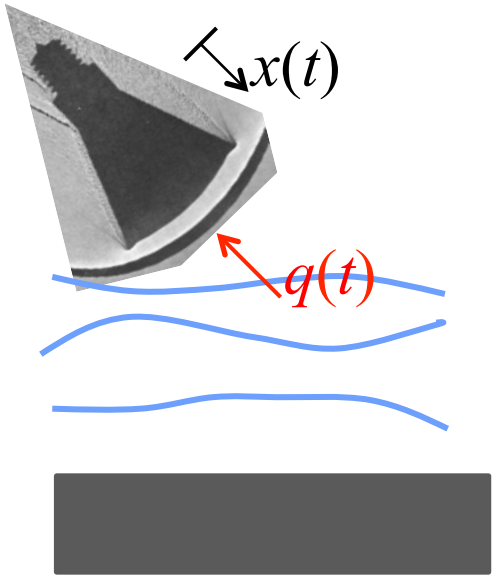
- **Experimental inputs (unmeasured) excite experimental responses – Five realizations**

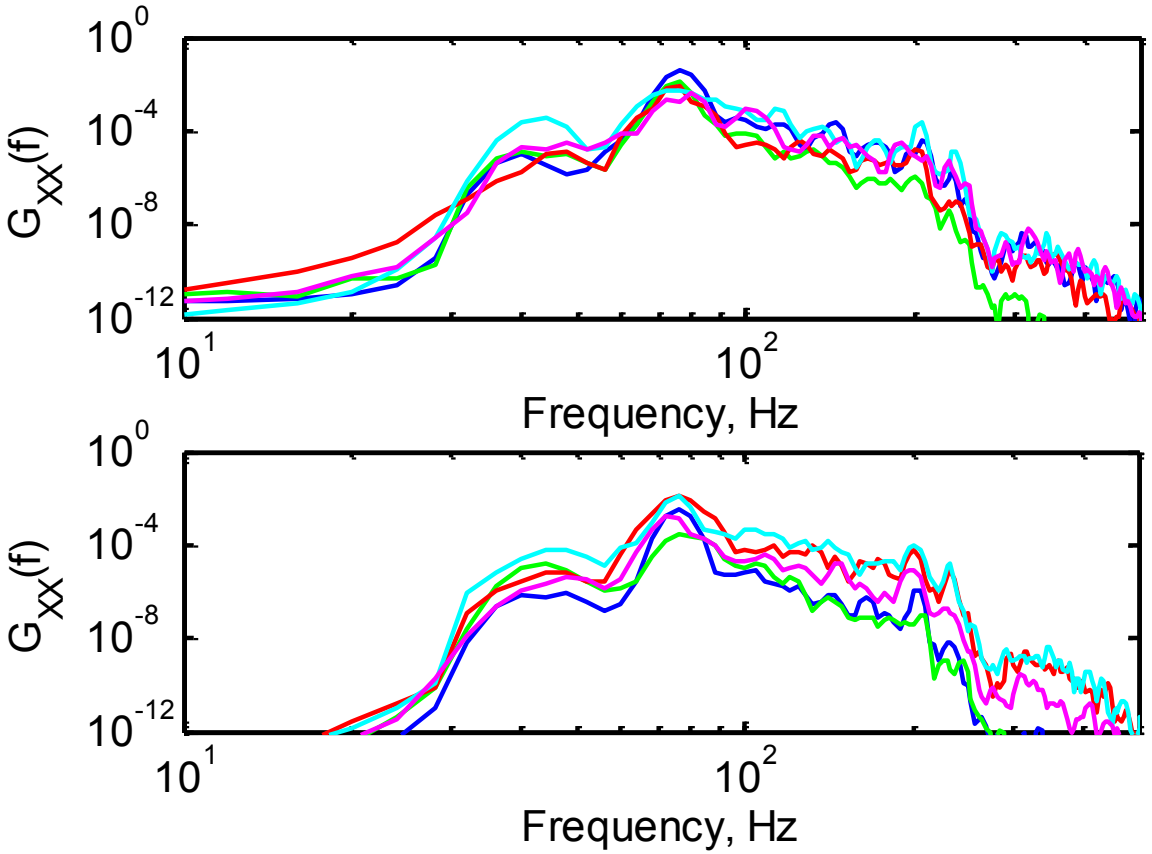




Environment Validation – Example

- **Experimental ESDs at times 1 sec, and 3 sec**





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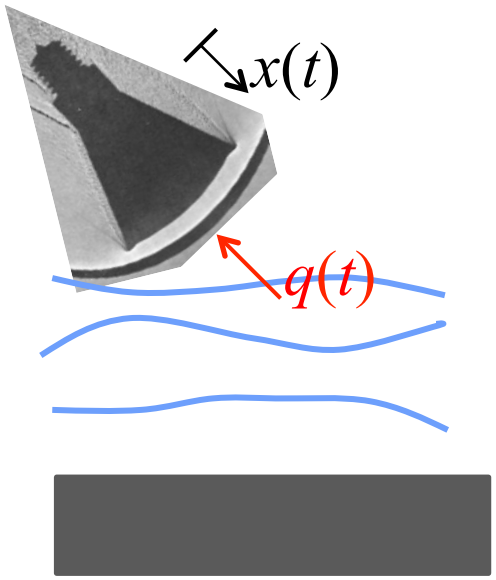
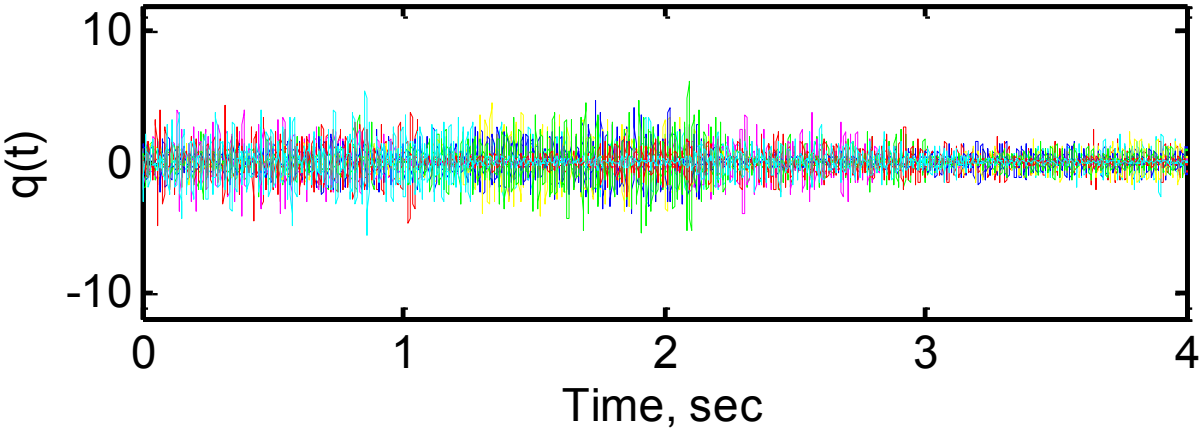
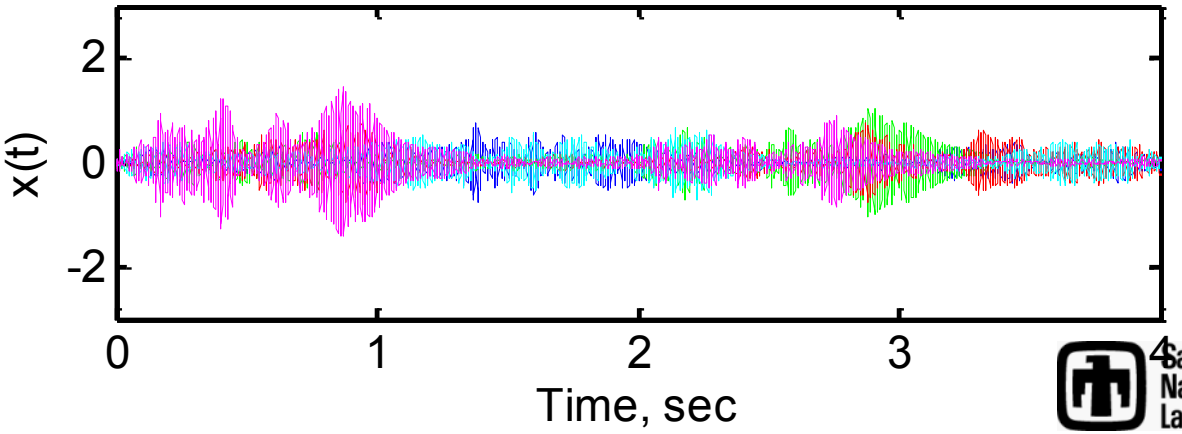
Environment Validation – Example

- **Model inputs (generated) and responses (computed) – Ten realizations**







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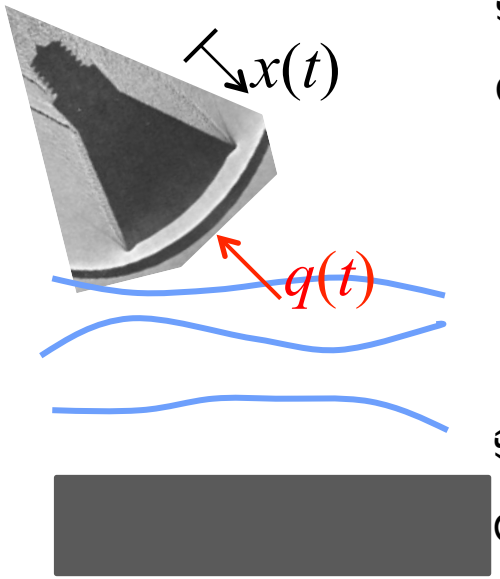
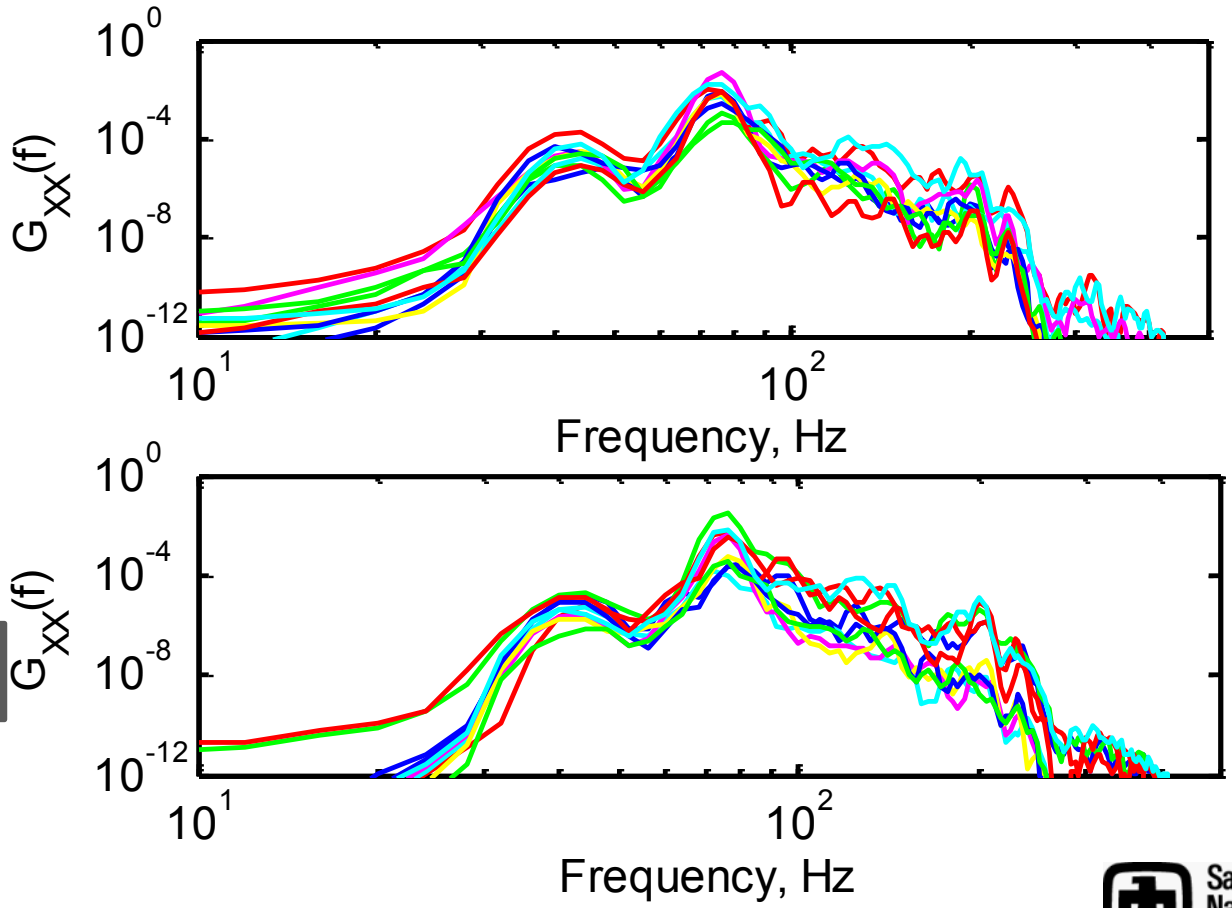
Environment Validation – Example

- **Spectra of computed responses at 1 sec, and 3 sec**





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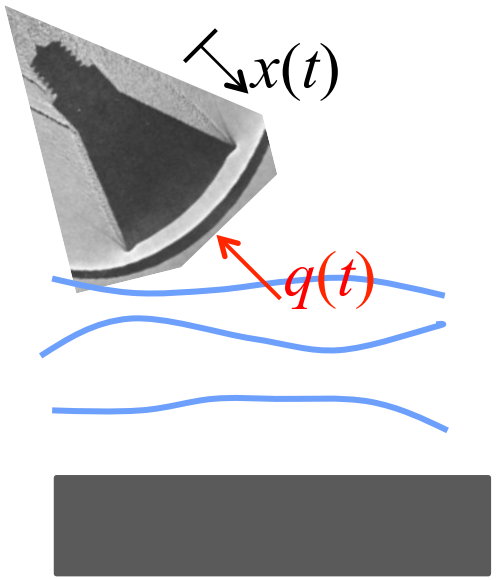
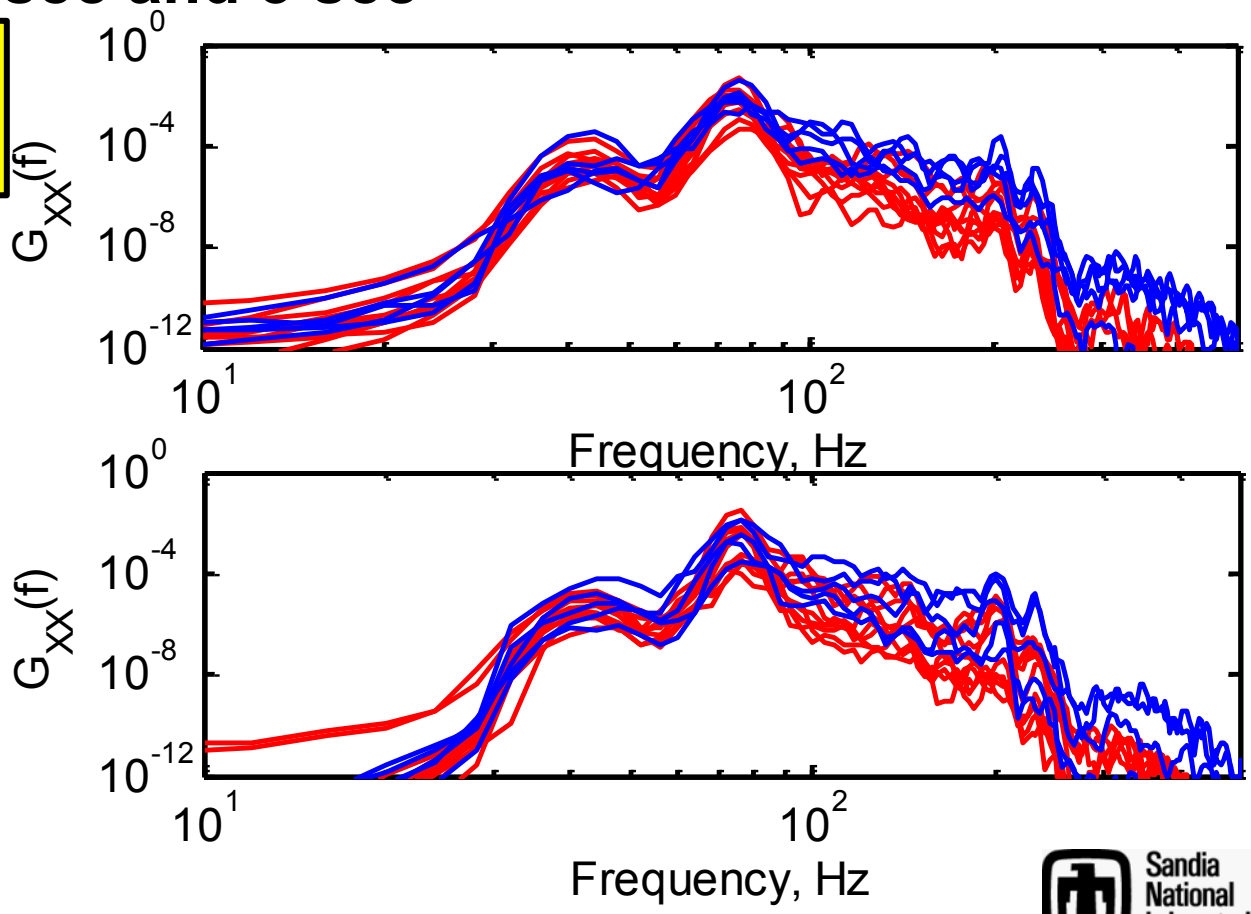
Environment Validation – Example

- **Experimental (blue) and model (red) response spectra at 1 sec and 3 sec**

Model spectra low at high frequencies





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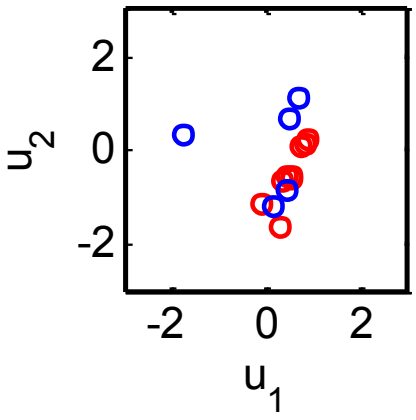
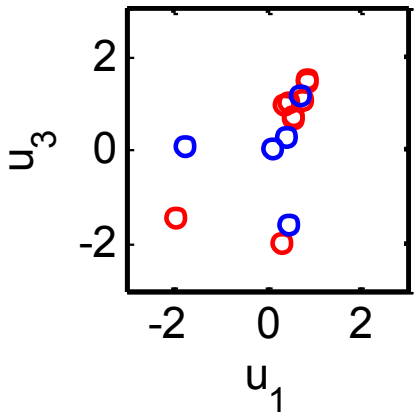
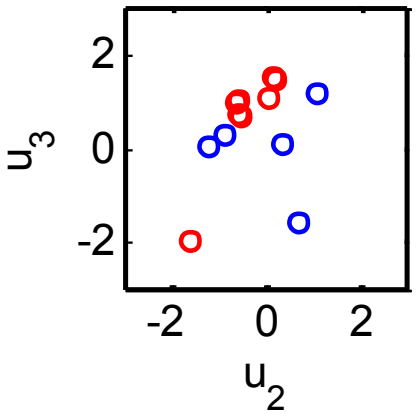
Environment Validation – Example

- Compute KLE of experiment, then u-values (blue)
- Compute u-values of model prediction - 1 sec







u2 versus u1 – Simulation not very good

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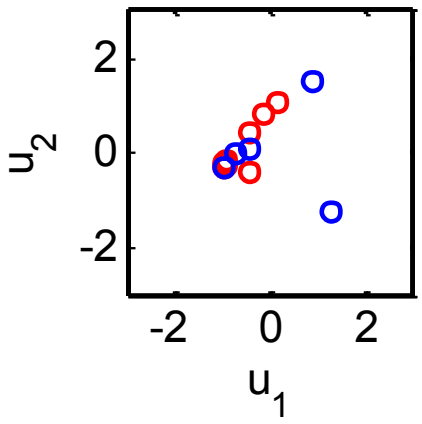
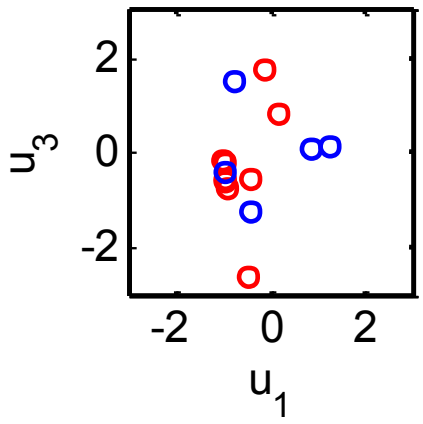
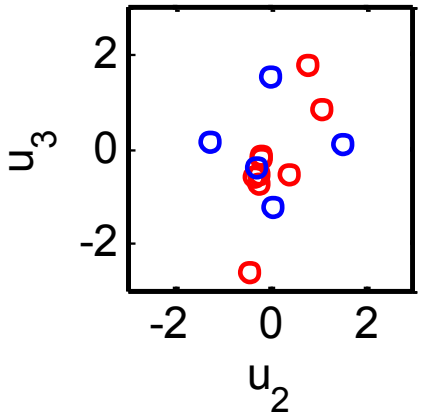
Environment Validation – Example

- 3 sec







Simulation better at 3 sec.

Summary

- **Method presented for validation of nonstationary random process environment**
  - **Based on evolutionary spectral density (ESD) from Priestley model**
  - **Karhunen-Loeve expansion (KLE) of ESDs obtained from measured experimental responses**
  - **Random variates of ESDs inferred from experiments**
  - **Random variates of model-generated responses obtained**
  - **Test of hypothesis performed – Can model-generated responses be rejected as products of experimental random process?**