

## PROBABILISTIC TEST/MODEL INTEGRATED ANALYSIS OF COMPOSITE MATERIALS AND STRUCTURES

Mark R. Gurvich, GurvicMR@utrc.utc.com  
Patrick L. Clavette, ClavetPL@utrc.utc.com  
Sorin Costiner, CostinS@utrc.utc.com  
United Technologies Research Center  
411 Silver Lane, MS 129-73  
East Hartford, CT 06108, USA

**Abstract.** *Experimental validations of modeling predictions are usually very expensive and time-consuming efforts even for relatively simple deterministic statements of analysis. In case of probabilistic analysis, this problem becomes even more difficult, since it may require numerous tests to generate large enough statistical populations. A solution to mitigate this challenge is developed in this study by considering large volume of measurements for each performed test. The developed approach is based on implementation of digital image correlation (DIC) technique and its integration with independent FEA modeling. According to DIC, the entire field of displacements is captured and quantified in contrast with more traditional test methods showing deformation of a few selected points only. These measured fields are considered as random functions and are compared with corresponding modeling predictions. The predictions are generated by FEA using either deterministic or probabilistic statements of modeling. A corresponding computational implementation is developed for efficient test/model integration and statistical assessment of conclusions including their confidence. Methodological challenges of the developed approach are summarized and discussed in detail. Demonstration of the developed capabilities is shown on example of composite sub-components under static load conditions. The robust nature of computational implementation is validated. It is also shown that generated statistical results provide additional advanced opportunities for a) interpretation of test results; b) critical evaluation of modeling assumptions; and c) generation of statistical data to quantify inevitable scatter of material/structural response. Although the demonstration of the approach is considered on example of composite structures, it can be equally recommended for other materials such as metals, polymers, elastomers, etc.*

**Keywords:** *composite, probabilistic analysis, testing, experimental validation, digital image correlation*

### 1. INTRODUCTION

Experimental characterization of complex aerospace structures is usually a very expensive and time-consuming process. Particular challenges are often associated with composite structures due to their heterogeneous design, anisotropy of material properties, complex network of damage patterns, etc. Thus, all efforts should be applied to maximize output of such testing with potential applicability of generated results to other similar systems or load scenarios. Digital image correlation (DIC) technique is among the most promising ways in this direction since DIC can generate another level of information unavailable in more traditional mechanical testing. Major advantage here is generation of high fidelity *functions* of displacements or strains rather than their *limited finite measurements* in conventional characterization. Opportunities of DIC-based experimental characterization are illustrated, for example, in recent works (Gurvich et al. (2013b); Gurvich and Clavette, 2013a) for composite structures and materials, respectively. Additional key advantage of DIC is associated with large statistical population of measurements providing invaluable opportunity to perform systematic probabilistic assessment and apply generated results to uncertainty quantification. This study describes and illustrates this advantage in detail for problems of test/model validation requiring probabilistic assessment.

### 2. APPROACH

Developed approach is schematically illustrated at Fig.1 and consists of three major inter-connected efforts. The first effort is focused on development and implementation of finite-element analysis (FEA) for a considered structural problem including its post-processing. The model shall be specifically developed to capture major expected outputs (e.g., strain concentrations in the vicinity of damage tips). Also, FEA mesh density shall be correlated, at least, qualitatively with expected strain or displacement gradients. The second effort is completely independent mechanical testing including DIC-based characterization of strain and displacement fields. Although these efforts seem to be standard computational and experimental exercises, their robust statistical comparison is a major challenge primarily due to inevitable a) statistical variability of measurements; b) differences in locations of considered points (i.e., between nodes in FEA and speckles in testing); and c) potential non-uniqueness of interpolations, especially (Gurvich, 2013c), in analysis of random strains. The third effort, therefore, is addressing probabilistic test/model integration including 1) selection of evaluation criteria (e.g., as a normalized gap between FEA and DIC); 2) its statistical treatment with

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**Stochastic Dynamic Response Analysis and Performance-Based Seismic Safety Evaluation for High Concrete Faced Rockfill Dams** Bin Xu,Rui Pang,2024-09-17 This open access book provides a complete probabilistic analysis method and a performance based seismic

safety evaluation for high concrete faced rockfill dam CFRD Combined with random sample generation and reliability analysis methods the dynamic response characteristics and reliability level of CFRD under various random factors are comprehensively described In Chapter 2 a random ground motion model based on spectral representation random function and a high dimensional random variable generation method based on GF discrepancy are established Combined with probability density evolution method PDEM and the random sample generation methods to verify its effectiveness and reliability for nonlinear complex geotechnical engineering In Chapter 3 the dynamic response and probabilistic characteristics of high CFRD under random ground motion are revealed based on the elastoplastic analysis A performance based seismic safety evaluation method is established In Chapter 4 the influence of material parameter randomness on dynamic response and seismic safety of high CFRD is studied from the perspective of stochastic dynamics and probability In Chapter 5 the stochastic dynamic response and probability distribution of high CFRD under the coupled random action of ground motion and material parameters are systematically studied and the performance based seismic safety evaluation framework is improved In Chapter 6 The stochastic dynamic response of 3D high CFRD is studied and the failure performance index and performance level based on overstress volume ratio combined with overstress accumulation time are discussed The performance based seismic safety evaluation framework is further improved In Chapter 7 combined with the finite element dynamic time history analysis method considering the softening effect of rockfill a performance based seismic safety evaluation framework for dam slope stability of high CFRD under multiple random factors is systematically explored from the perspective of stochastic dynamics and probability In Chapter 8 The performance indexes of seismic safety evaluation for high CFRDs are suggested and the corresponding performance level with probability assurance is put forward The multi seismic intensity multi performance target failure probability performance relationship is established and a performance based seismic safety evaluation framework is initially formed This book can be used as a reference for scholars studying random vibration and reliability analysis as well as for scholars studying dam safety evaluation

Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting United States. Bureau of Mines,1980

Probabilistic Analysis and Density Parameter Estimation Within Necessus ,2002 Probabilistic Structural Mechanics: Advances in Structural Reliability Methods Pol D. Spanos,Y.-T. Wu,2013-03-13 This symposium is the seventh of a series of IUTAM sponsored symposia which focus on probabilistic methods in mechanics It is the sequel to the series of meetings in Coventry UK 1972 Southampton UK 1976 Frankfurt Oder Germany 1982 Stockholm Sweden 1984 Innsbruck Igls Austria 1987 and Turin Italy 1991 The symposium focused on advances in the area of probabilistic mechanics with direct application to structural reliability issues The contributed papers address collectively the four components of a structural reliability problem They are characterization of stochastic loads description of material properties in terms of fatigue and fracture response determination and quantitative assessment of the reliability of the structural system Four Keynote Lectures by V

Bolotin Russia o Ditlevsen Denmark R Heller USA and F Ziegler Austria were delivered the remaining contributed papers were organized in ten technical sessions A reception was hosted by Dr Y Wu the first day of the symposium the second day of the symposium a banquet was hosted by Dr P Spanos with Dr N Abramson serving as the banquet speaker Closing remarks were provided by the IUTAM Secretary General Dr F Ziegler

*A Compendium of Neuropsychological Tests* Otfried Spreen, Esther Strauss, 1998-02-19 In a survey of neuropsychologists published in *The Clinical Neuropsychologist* the first edition of the Compendium was named as one of the eleven essential books in their field This second edition has been thoroughly updated to cover new developments in neuroscience cognitive psychology and psychological assessment It includes new chapters on test selection report writing and informing the client executive functions occupational interest and aptitude and the assessment of functional complaints In addition to updating research findings about the tests covered in the first edition the book now contains almost twice as many tests

Linear Models for Optimal Test Design Wim J. van der Linden, 2006-01-01 Over my nearly forty years of teaching and conducting research in the field of psychometric methods I have seen a number of major technical advances that respond to pressing educational and psychological measurement problems The development of criterion referenced assessment was the first beginning in the late 1960s with the important work of Robert Glaser and Jim Popham in response to the need for assessments that considered candidate performance in relation to a well defined body of knowledge and skills rather than in relation to a norm group The development of criterion referenced testing methodology with a focus on decision theoretic concepts and methods content validity standard setting and the recognition of the merits of both criterion norm referenced and criterion referenced assessments has tremendously influenced current test theory and testing The second major advance was the introduction of item response theory IRT and associated models and their applications to replace classical test theory CTT and related practices Beginning slowly in the 1940s and 1950s with the pioneering work of Frederic Lord Allan Birnbaum and Georg Rasch by the 1970s the measurement journals were full of important research studies describing new IRT models technical advances in model parameter estimation and model fit and research on applications of IRT models to equating test development the detection of potentially biased test items and adaptive testing The overall goal has been to improve and expand measurement practices by overcoming several shortcomings of classical test theory dependence of test item statistics and reliability estimates on examinee samples dependence of examinee true score estimates on the particular choices of test items and the limitation in CTT of modeling examinee performance at the test level rather than at the item level

*A Handbook of Process Tracing Methods* Michael Schulte-Mecklenbeck, Anton Kuehberger, Joseph G. Johnson, 2019-06-10 A Handbook of Process Tracing Methods demonstrates how to better understand decision outcomes by studying decision processes through the introduction of a number of exciting techniques Decades of research have identified numerous idiosyncrasies in human decision behavior but some of the most recent advances in the scientific study of decision making involve the development of sophisticated methods

for understanding decision process known as process tracing In this volume leading experts discuss the application of these methods and focus on the best practices for using some of the more popular techniques discussing how to incorporate them into formal decision models This edition has been expanded and thoroughly updated throughout and now includes new chapters on mouse tracking protocol analysis neurocognitive methods the measurement of valuation as well as an overview of important software packages The volume not only surveys cutting edge research to illustrate the great variety in process tracing techniques but also serves as a tutorial for how the novice researcher might implement these methods A Handbook of Process Tracing Methods will be an essential read for all students and researchers of decision making

**Statistics in the Health Sciences** Albert Vexler, Alan Hutson, 2018-01-19 This very informative book introduces classical and novel statistical methods that can be used by theoretical and applied biostatisticians to develop efficient solutions for real world problems encountered in clinical trials and epidemiological studies The authors provide a detailed discussion of methodological and applied issues in parametric semi parametric and nonparametric approaches including computationally extensive data driven techniques such as empirical likelihood sequential procedures and bootstrap methods Many of these techniques are implemented using popular software such as R and SAS Vlad Dragalin Professor Johnson and Johnson Spring House PA It is always a pleasure to come across a new book that covers nearly all facets of a branch of science one thought was so broad so diverse and so dynamic that no single book could possibly hope to capture all of the fundamentals as well as directions of the field The topics within the book s purview fundamentals of measure theoretic probability parametric and non parametric statistical inference central limit theorems basics of martingale theory Monte Carlo methods sequential analysis sequential change point detection are all covered with inspiring clarity and precision The authors are also very thorough and avail themselves of the most recent scholarship They provide a detailed account of the state of the art and bring together results that were previously scattered across disparate disciplines This makes the book more than just a textbook it is a panoramic companion to the field of Biostatistics The book is self contained and the concise but careful exposition of material makes it accessible to a wide audience This is appealing to graduate students interested in getting into the field and also to professors looking to design a course on the subject Aleksey S Polunchenko Department of Mathematical Sciences State University of New York at Binghamton This book should be appropriate for use both as a text and as a reference This book delivers a ready to go well structured product to be employed in developing advanced courses In this book the readers can find classical and new theoretical methods open problems and new procedures The book presents biostatistical results that are novel to the current set of books on the market and results that are even new with respect to the modern scientific literature Several of these results can be found only in this book

**Proceedings of the U.S. Nuclear Regulatory Commission ... Water Reactor Safety Research Information Meeting** ,1987 **Indexes to Survey Methodology Literature** United States. Bureau of the Census,1974 **Title List of Documents Made Publicly Available** , Technical Paper ,1974 **Fluid**

**Structure Interaction and Moving Boundary Problems IV** Subrata Kumar Chakrabarti, C. A. Brebbia, 2007 Publishing papers presented at the Fourth International Conference on Fluid Structure Interactions this book features contributions from experts specialising in this field on new ideas and the latest techniques A valuable addition to this successful series and will be of great interest to mechanical and structural engineers offshore engineers earthquake engineers naval engineers and any other experts involved in topics related to fluid structure interaction Topics covered include Hydrodynamic Forces Response of Structures including Fluid Dynamic Offshore Structure and Ship Dynamics Fluid Pipeline Interactions Structure Response to Shock and Blast Loading Vortex Shedding and Flow Induced Vibrations Cavitations Effects in Turbo Machines and Pumps Wind Effects on Bridges and Tall Structures Mechanics of Cables Rivers and Moorings Building Biofluids and Biological Tissue Interaction Problems in CFD Experimental Studies and Validation Vibrations and Noise Free Surface Flows and Moving Boundary Problems

**Test Fraud** Neal Kingston, Amy Clark, 2014-06-27 There has been an increase in awareness and perhaps occurrence of individual and organized cheating on tests Recent reports of widespread problems with state student accountability tests and teacher certification testing have raised questions about the very validity of assessment programs While there are several books that specifically detail the issues of test security cheating on assessments few outline the statistical procedures used for detecting various types of potential test fraud and the associated research findings Without a significant research literature base the new generation of researchers will have little opportunity or incentive to improve on existing methods Enlisting a variety of experts and scholars in different fields of testing this edited volume expands on the current literature base by including examples of detailed research findings arrived at by statistical methodology It also provides a synthesis of the current state of the art with regard to the statistical detection of testing infidelity particularly for large scale assessments By presenting methods currently used by testing organizations and research on new methods the volume offers an important forum for expanding the literature in this area

**Handbook of Item Response Theory** Wim J. van der Linden, 2018-02-19 Drawing on the work of 75 internationally acclaimed experts in the field Handbook of Item Response Theory Three Volume Set presents all major item response models classical and modern statistical tools used in item response theory IRT and major areas of applications of IRT in educational and psychological testing medical diagnosis of patient reported outcomes and marketing research It also covers CRAN packages WinBUGS Bilog MG Multilog Parscale IRTPRO Mplus GLLAMM Latent Gold and numerous other software tools A full update of editor Wim J van der Linden and Ronald K Hambleton's classic Handbook of Modern Item Response Theory this handbook has been expanded from 28 chapters to 85 chapters in three volumes The three volumes are thoroughly edited and cross referenced with uniform notation format and pedagogical principles across all chapters Each chapter is self contained and deals with the latest developments in IRT

*Modulation of Neuronal Responses* Giedrius T. Buračas, 2003

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