



AFRL-RW-EG-TP-2011-009

BROADBAND STRUCTURAL DYNAMICS: UNDERSTANDING
THE IMPULSE-RESPONSE OF STRUCTURES ACROSS
MULTIPLE LENGTH AND TIME SCALES

Alain Beliveau
Applied Research Associates, Inc.
Niceville, FL 32578

Jason Foley, Curtis McKinion, Janet Wolfson
Air Force Research Laboratory, Munitions Directorate
Eglin AFB, FL 32542

Jacob Dodson, Dan Inman
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

Andrew Dick
Rice University
Houston, TX 77251

AFOSR Intramural Research Task 09RW01COR

August 2010

Conference Poster

This poster was presented at the 2010 AFOSR Structural Mechanics Program review. One or more of the authors is a U.S. Government employee working within the scope of his/her position; therefore, the U.S. Government is joint owner of this work.

This paper is published in the interest of the Scientific and Technical Information exchange. Publication of this paper does not constitute approval or disapproval of the ideas or findings.

DISTRIBUTION A. Approved for public release; distribution unlimited. 96 ABW-2010-0469, 17 August 2010.

**AIR FORCE RESEARCH LABORATORY
MUNITIONS DIRECTORATE**

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Service, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 18 August 2010		2. REPORT TYPE Conference Poster		3. DATES COVERED (From - To) Aug 2009 - Aug 2010	
4. TITLE AND SUBTITLE BROADBAND STRUCTURAL DYNAMICS: UNDERSTANDING THE IMPULSE-RESPONSE OF STRUCTURES ACROSS MULTIPLE LENGTH AND TIME SCALES				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER 09RW01COR	
				5c. PROGRAM ELEMENT NUMBER 61102F	
6. AUTHOR(S) Alain Beliveau, Jason Foley, Curtis McKinion, Janet Wolfson, Jacob Dodson, Dan Inman, Andrew Dick				5d. PROJECT NUMBER 2302	
				5e. TASK NUMBER DW	
				5f. WORK UNIT NUMBER 92	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Applied Research Associates, Inc., Niceville, FL 32578 Air Force Research Laboratory, Munitions Directorate, Eglin AFB, FL 32542 Virginia Polytechnic Institute and State University, Blacksburg, VA 24061 Rice University, Houston, TX 77251				8. PERFORMING ORGANIZATION REPORT NUMBER AFRL-RW-EG-TP-2011-009	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory, Munitions Directorate AFRL/RWMF Eglin AFB, FL 32542-6810				10. SPONSOR/MONITOR'S ACRONYM(S) AFRL-RW-EG	
				11. SPONSORING/MONITORING AGENCY REPORT NUMBER SAME AS BLOCK 8	
12. DISTRIBUTION AVAILABILITY STATEMENT DISTRIBUTION A. Approved for public release, distribution unlimited 96 ABW-2010-0469, 17 August 2010.					
13. SUPPLEMENTARY NOTES See 'cover page' for pertinent metadata information.					
14. ABSTRACT The Broadband Analysis of Structural Harsh Environment Dynamics (BASHED) research program seeks to improve computational accuracy in simulations, develop structural health monitoring approaches, and characterize interface dynamics in impact and penetration environments. This poster outlines the annual progress in this effort in four research areas: (1) structural health monitoring, (2) experimental structural dynamics, (3) spectral modeling of wave propagation, and (4) wavelet analysis for damage detection.					
15. SUBJECT TERMS Structural health monitoring, damage detection, wavelets, structural dynamics, spectral element modeling, impact, shock, basic research					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UL	18. NUMBER OF PAGES 1	19a. NAME OF RESPONSIBLE PERSON Jason R. Foley
a. REPORT UNCLAS	b. ABSTRACT UNCLAS	c. THIS PAGE UNCLAS			19b. TELEPHONE NUMBER (Include area code) 850-883-0584



(09RW01COR) Broadband Structural Dynamics: Understanding the Impulse-Response of Structures Across Multiple Length and Time Scales



Alain Beliveau
Applied Research Associates, Inc.
Niceville, Florida

Jason Foley (PI), Curtis McKinion, and Janet Wolfson
Air Force Research Laboratory Munitions Directorate
Eglin Air Force Base, Florida

Jacob Dodson and Dan Inman
Virginia Tech
Blacksburg, Virginia

Andrew Dick
Rice University
Houston, Texas

Status Quo

Background

- Extreme impulsive loading in impact
- High magnitude forces (>>1 MN)
- Short duration (<1 ms) impulse and high frequency (>100 kHz) content

Technical Challenges

Computational Simulation of Impact and Penetration

- Poor numerical accuracy over entire event
- Limited bandwidth
- No predictive analyses for substructures/components
- Lack of high quality validation data

Structural Health Monitoring

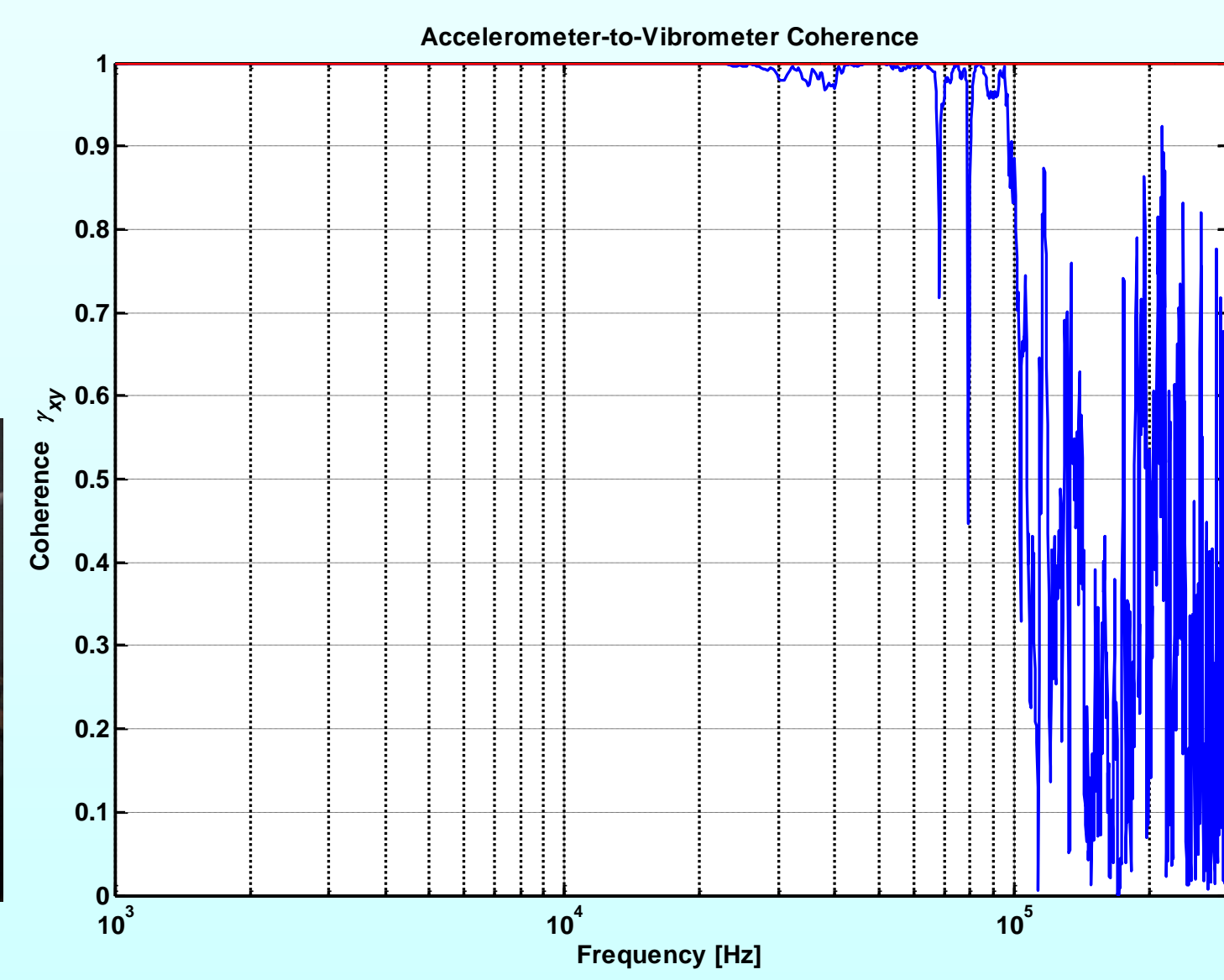
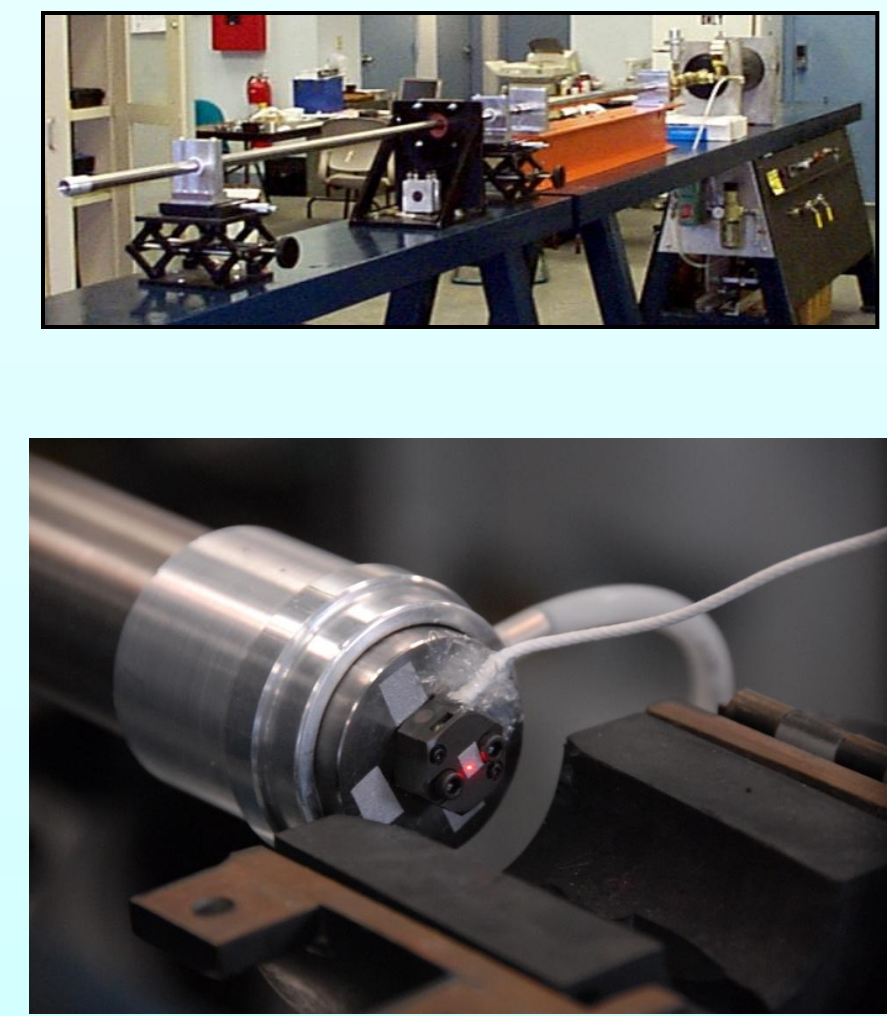
- Sample times typically seconds, minutes, hours
- Requires high-fidelity baseline

Interface Dynamics

- Poorly handled interfaces reduce simulation confidence margins
- Diversity of parameters makes classification difficult: roughness, preload, materials, lubrication...

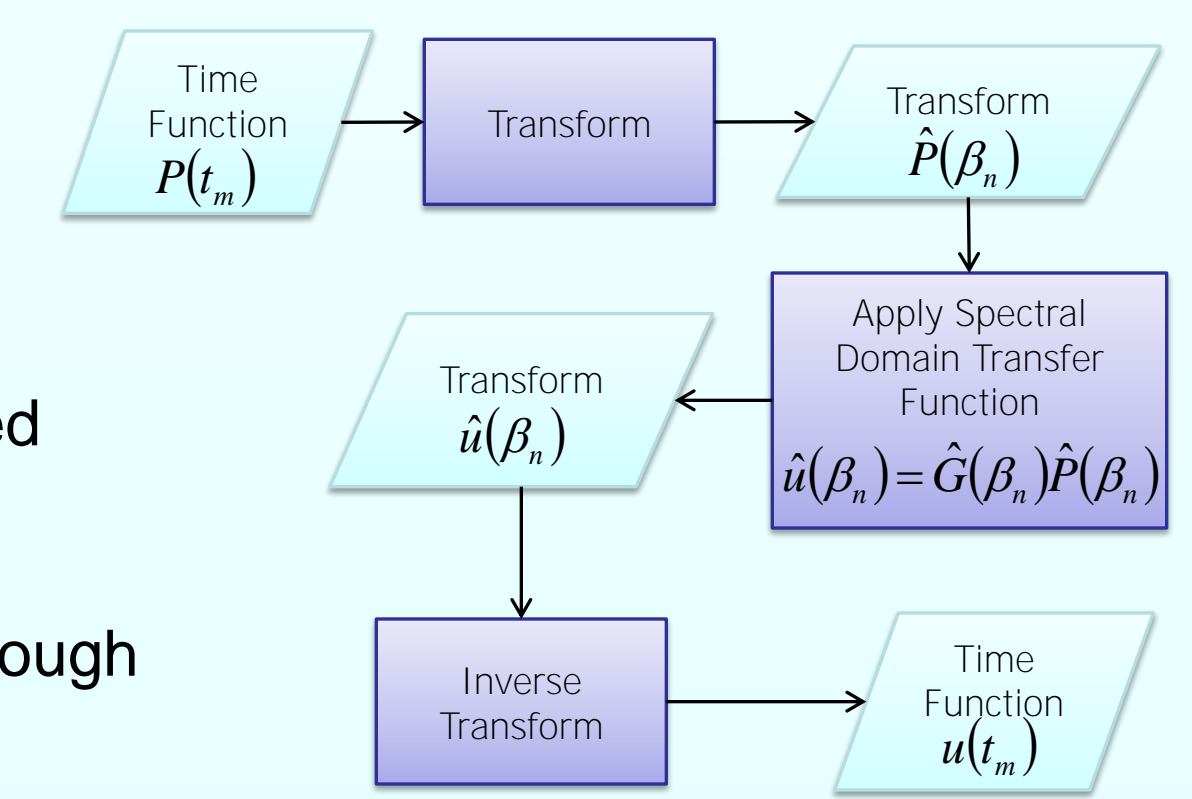
Approach 2: Experimental Structural Dynamics

- Non-contact laser doppler velocity system with broadband sensors
- Side-by-side coherence of ~100 kHz, beating best published results
- Understanding of cross-axis sensitivity and local resonances in response

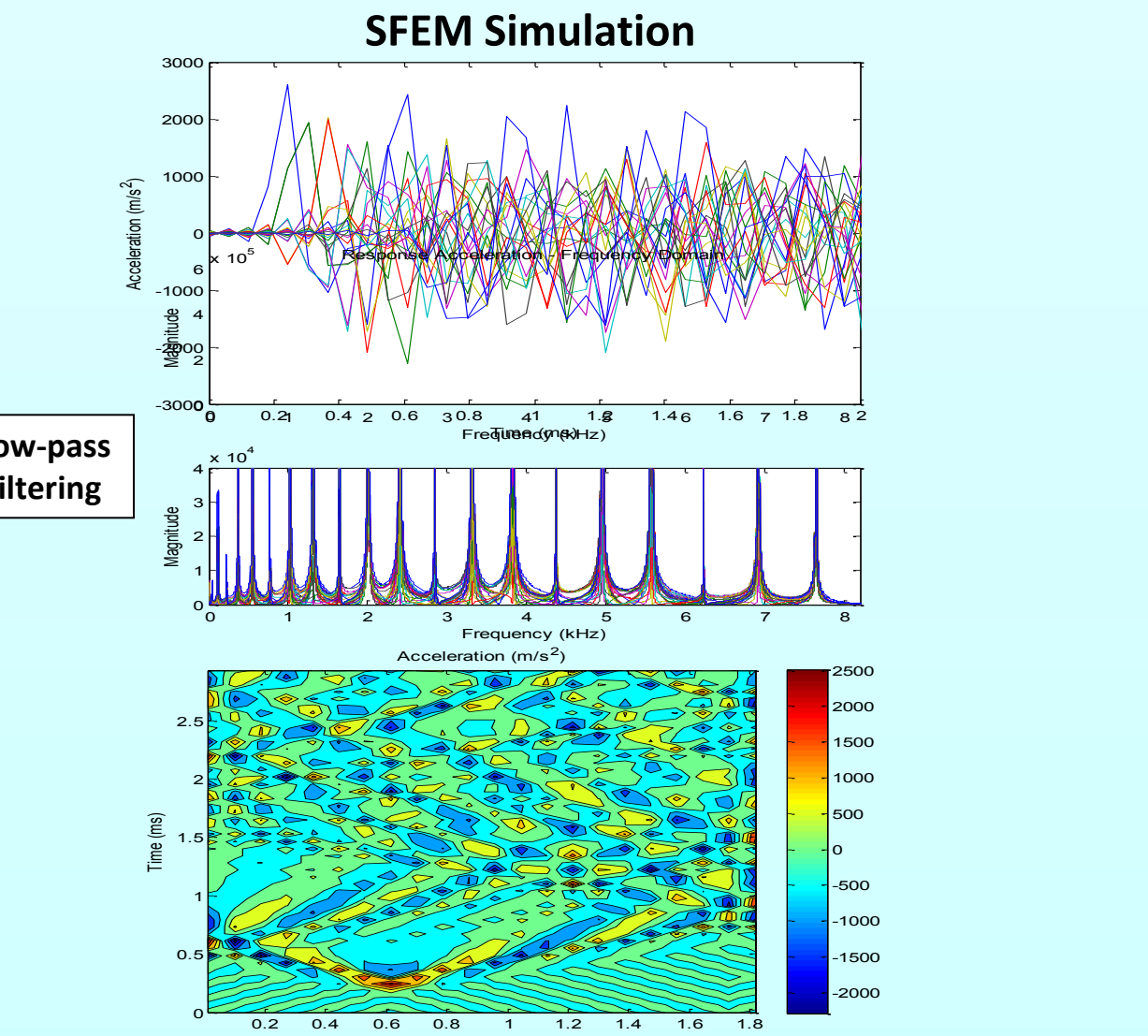
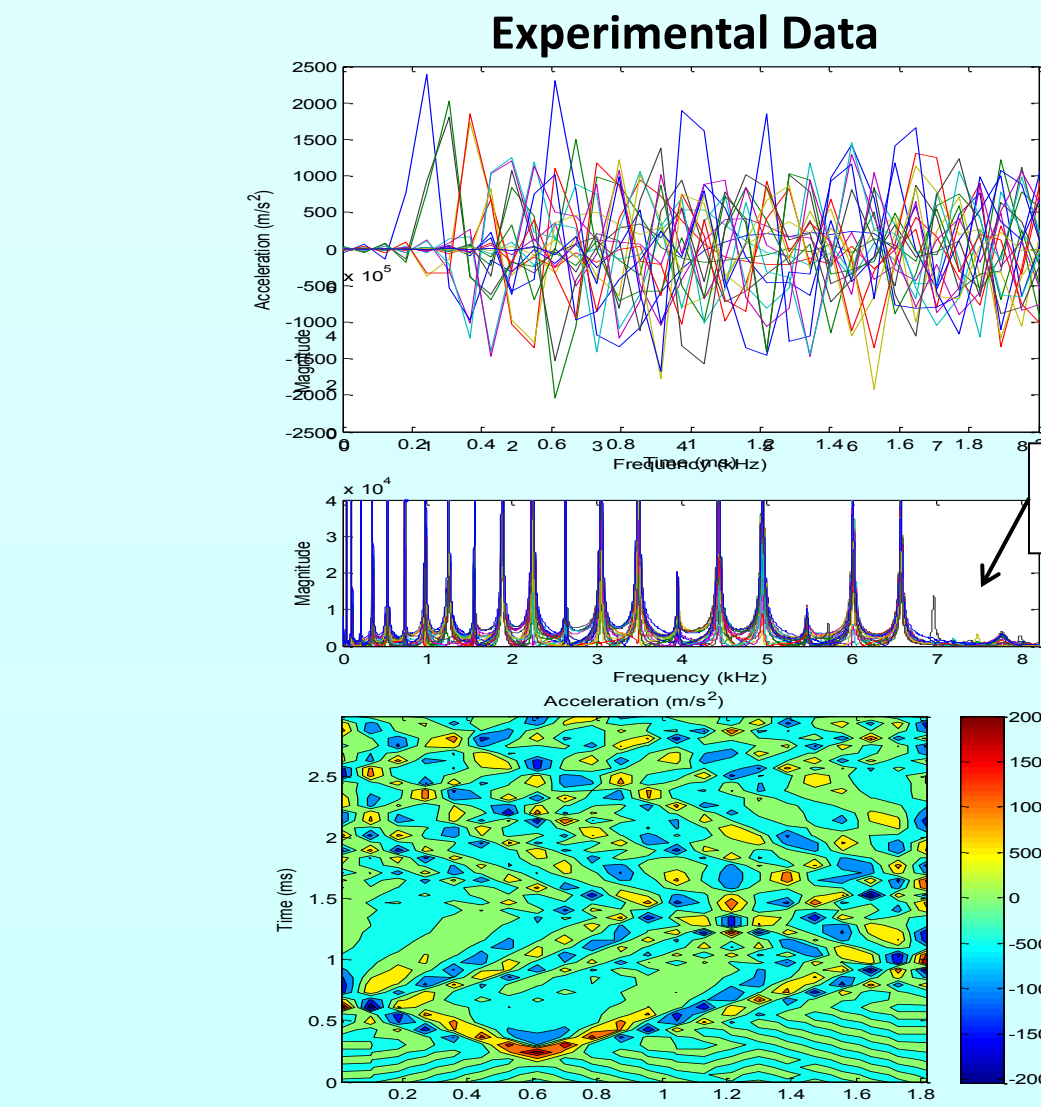
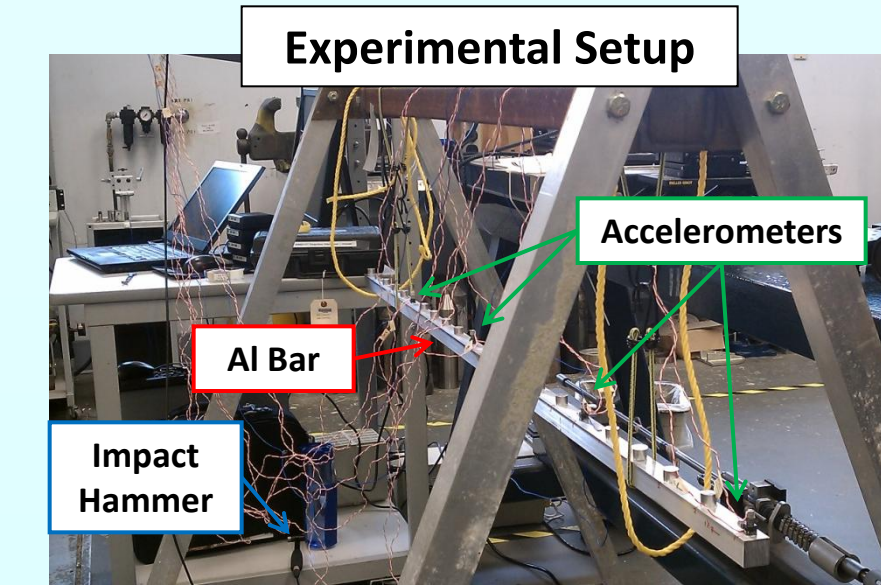
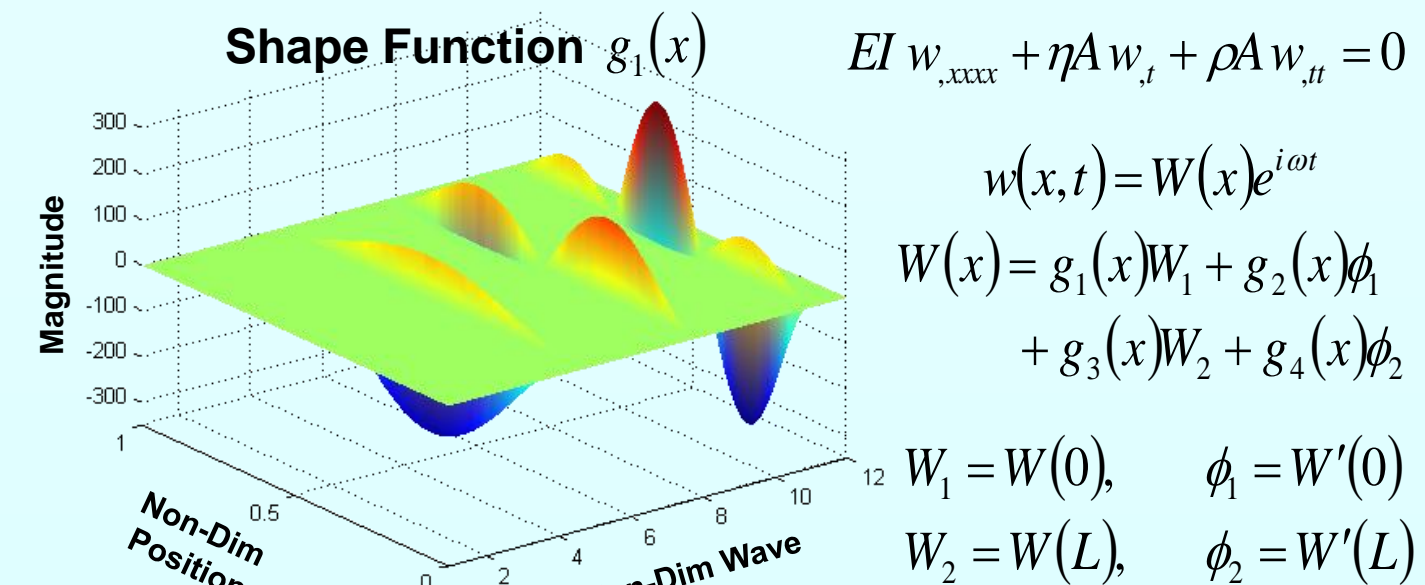


Approach 3: Spectral Modeling of Wave Propagation

- Input load is transformed into spectral domain
- Spectral domain response calculated
- Time domain response obtained through inverse transform



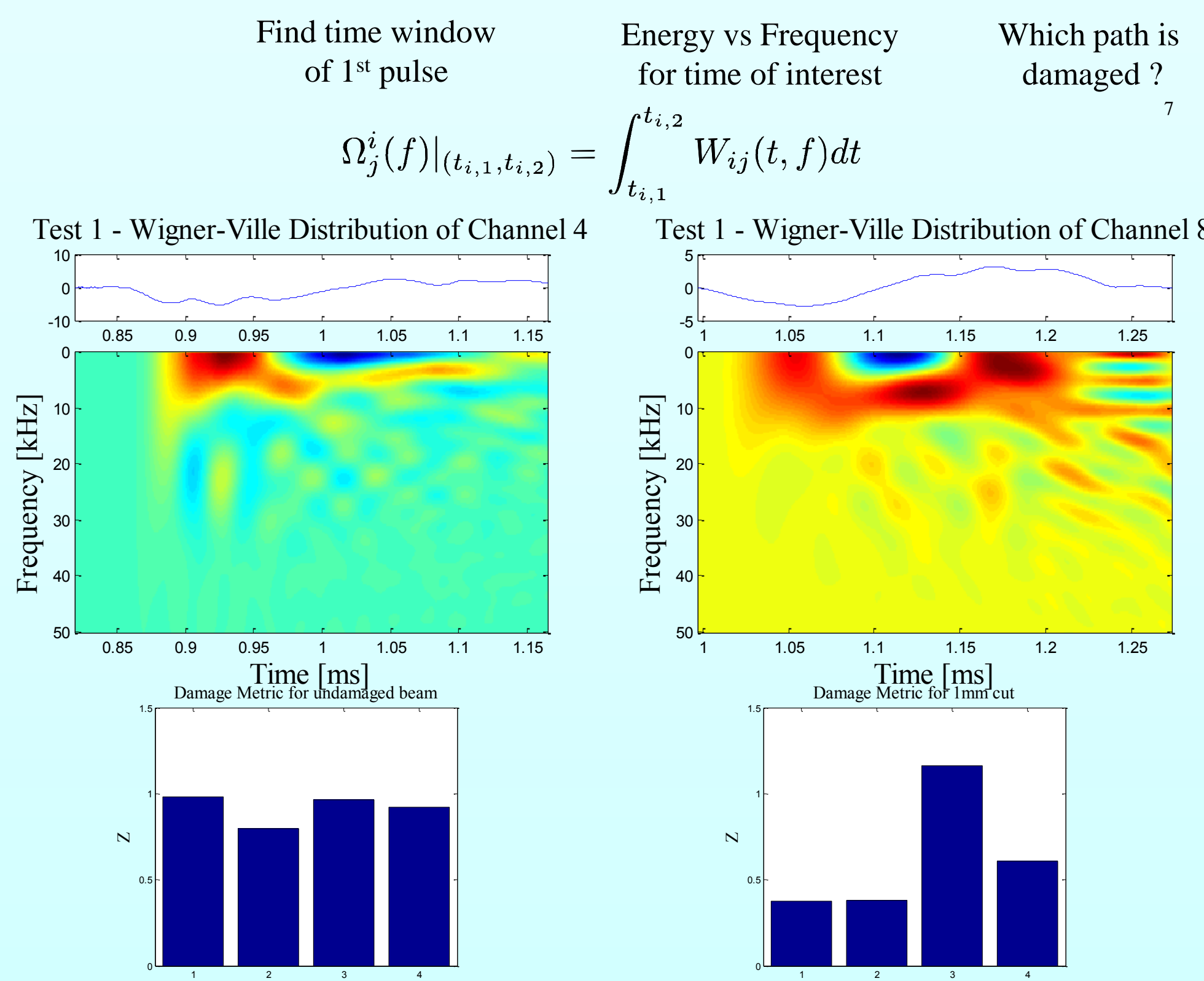
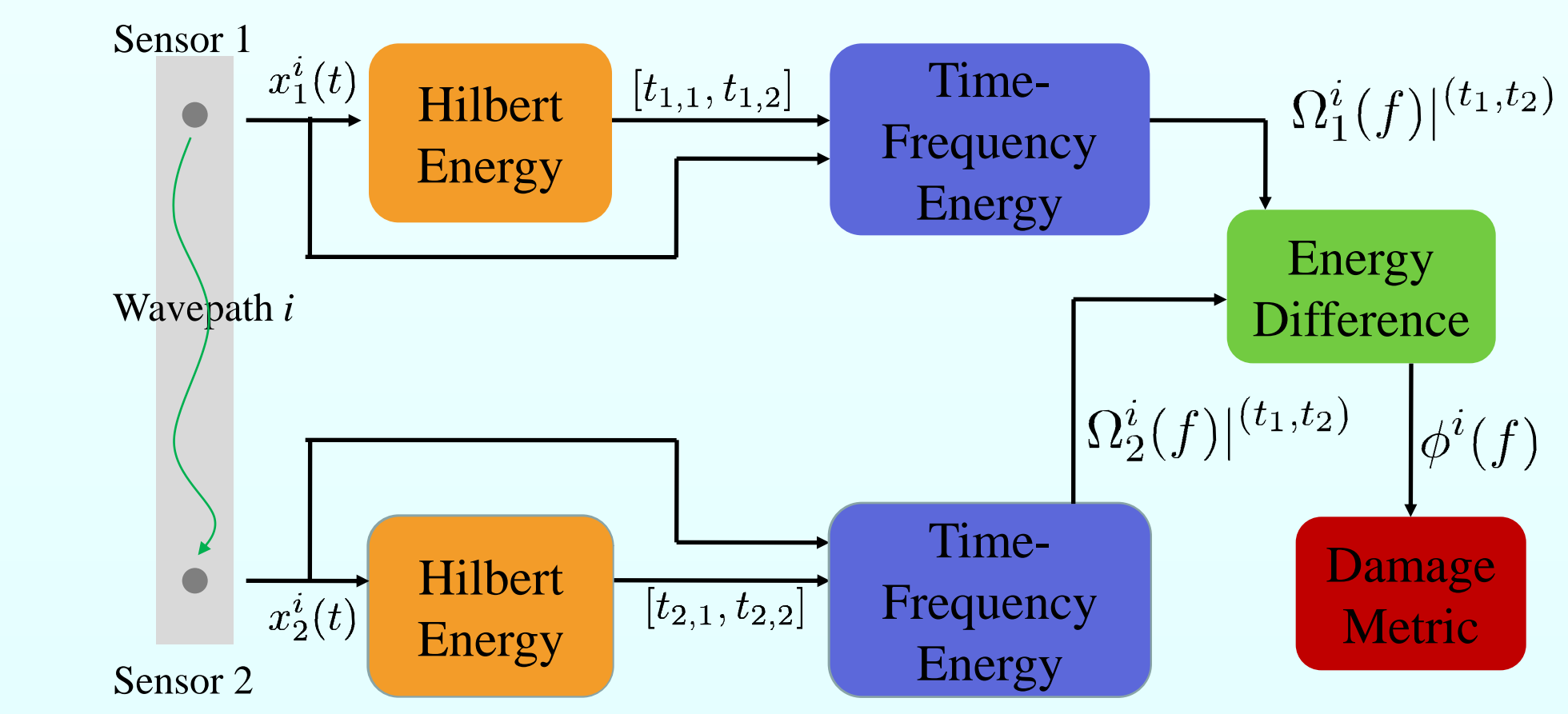
Euler-Bernoulli beam model



Achievements and Insight

Approach 1: Structural Health Monitoring

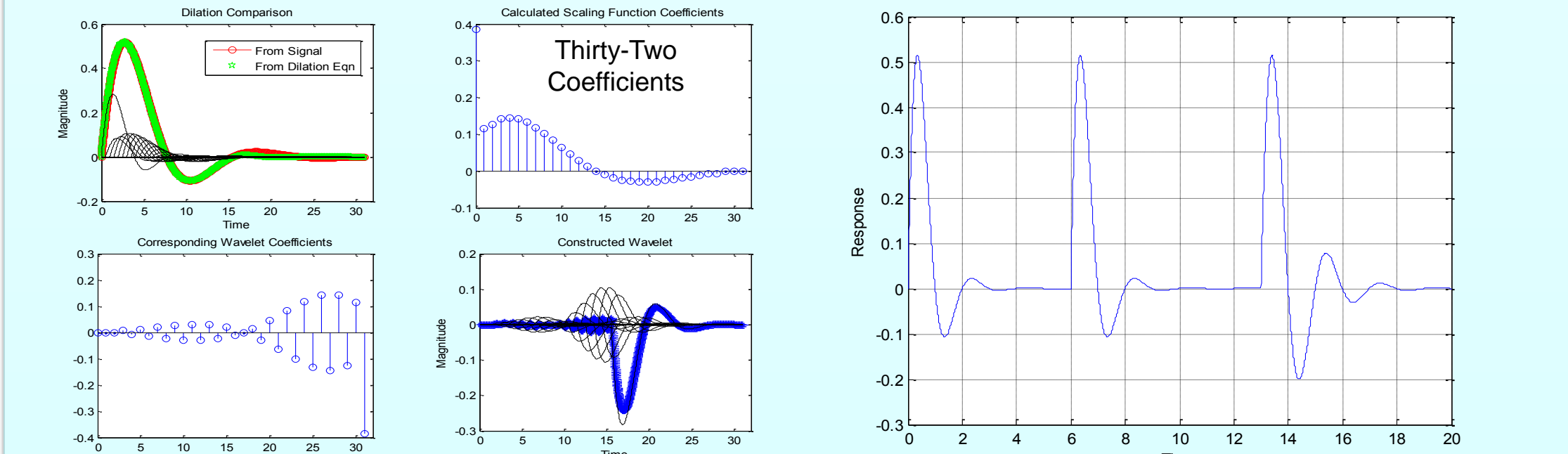
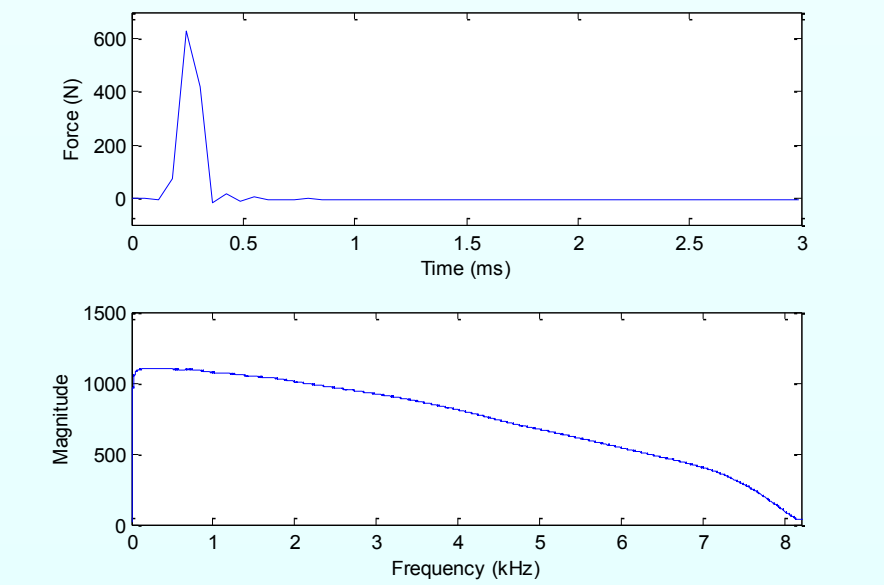
- Successfully developed baseline-free passive damage detection scheme
- Can detect cut/crack damage perpendicular to longitudinal wave



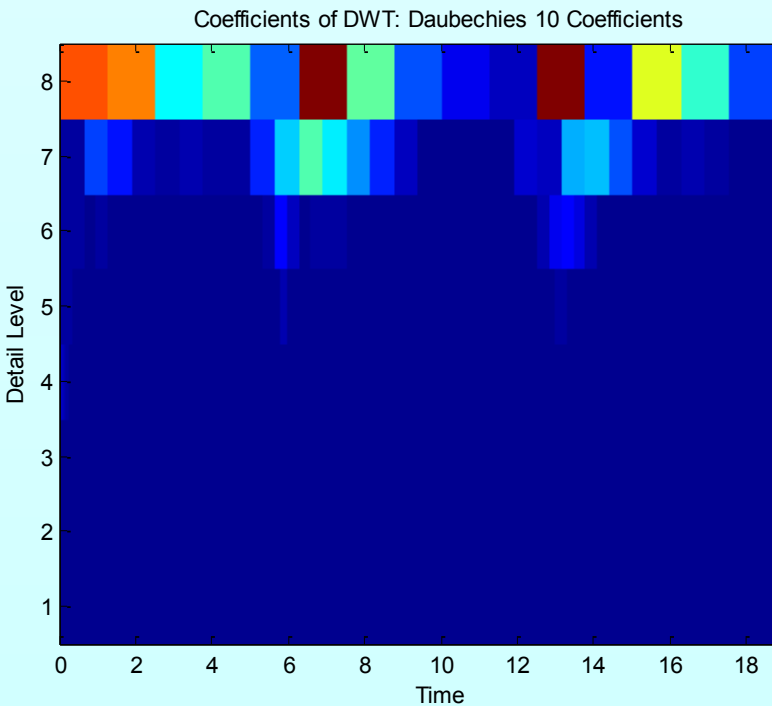
Dodson et al., "SHM of an Impulsively Loaded Structure Using a Wave-Propagation Based Instantaneous Baseline", Proc. SPIE Smart Structures/NDE, San Diego, CA, March 10, 2010.

Approach 4: WASABI Wavelet Analysis of Structural Anomalies using Baseline Impulse-Response

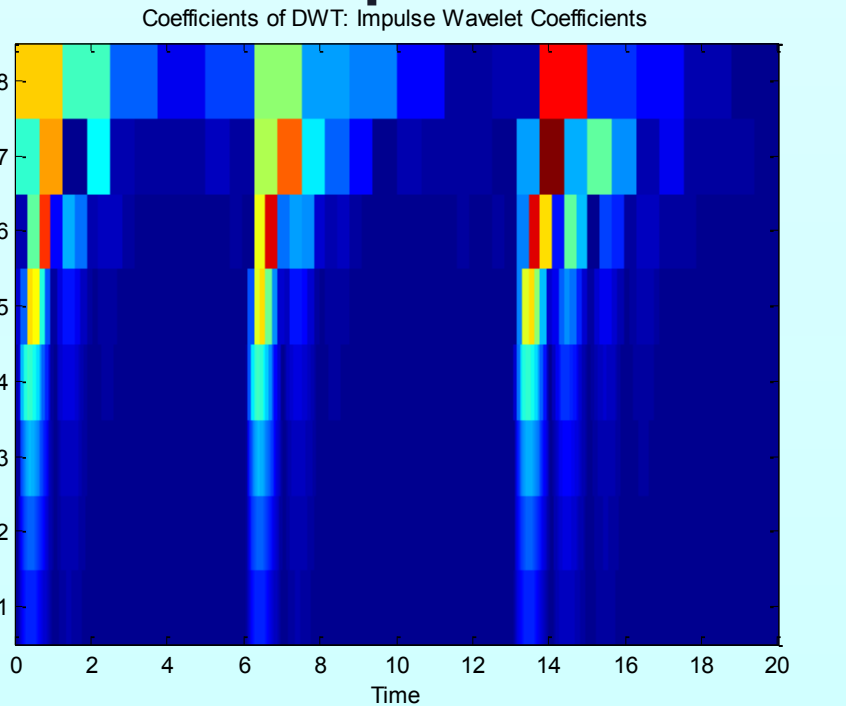
- Develop impulse response-based wavelets for signal analysis and modeling
 - Localized waveform
 - Energy content bounded
 - Ideal for studying localized signals
- Discrete Wavelet Generation
 - Detail coefficients (wavelet) ~ high frequency
 - Approximation coefficients (scaling function) ~ low frequency
- Calculate coefficients h of scaling function
 - Utilize pseudo-inverse of matrix



DWT w/ DB10 Wavelet



DWT w/ Impulse Wavelet



- Better resolution of differences at unity scale!

Current Impact

- Nearly arbitrary (10^4+) increase in computational propagation of stress waves
- Identification of low-level damage (10% stiffness) in early (10 ms) transient response of structures

Planned Impact

- New element families and code architectures for hydrocodes
- Improved broadband modeling of all levels of structural response
- Instantaneous identification of damage in structures

Research Goals

- Increase experimental coherence of co-located sensors beyond 100 kHz
- Identify damage within 1 ms of onset in hardened structures
- Accurately propagate shock waves over multiple interfaces for >10 ms

Acknowledgements

- AFOSR & ASEE for Sumer Faculty Fellowship Program support of Prof. Dick
- Science, Mathematics, And Research for Transformation (SMART) Scholarship for Service for Jacob Dodson
- David Stargel (AFOSR/NA) for intramural research funding

Achievements and Insight

Quantitative Impact

End-of-Phase Goal