Current Methodology for

Dynamic Stress-Strain Prediction for Structural Health Monitoring and System Load Prediction

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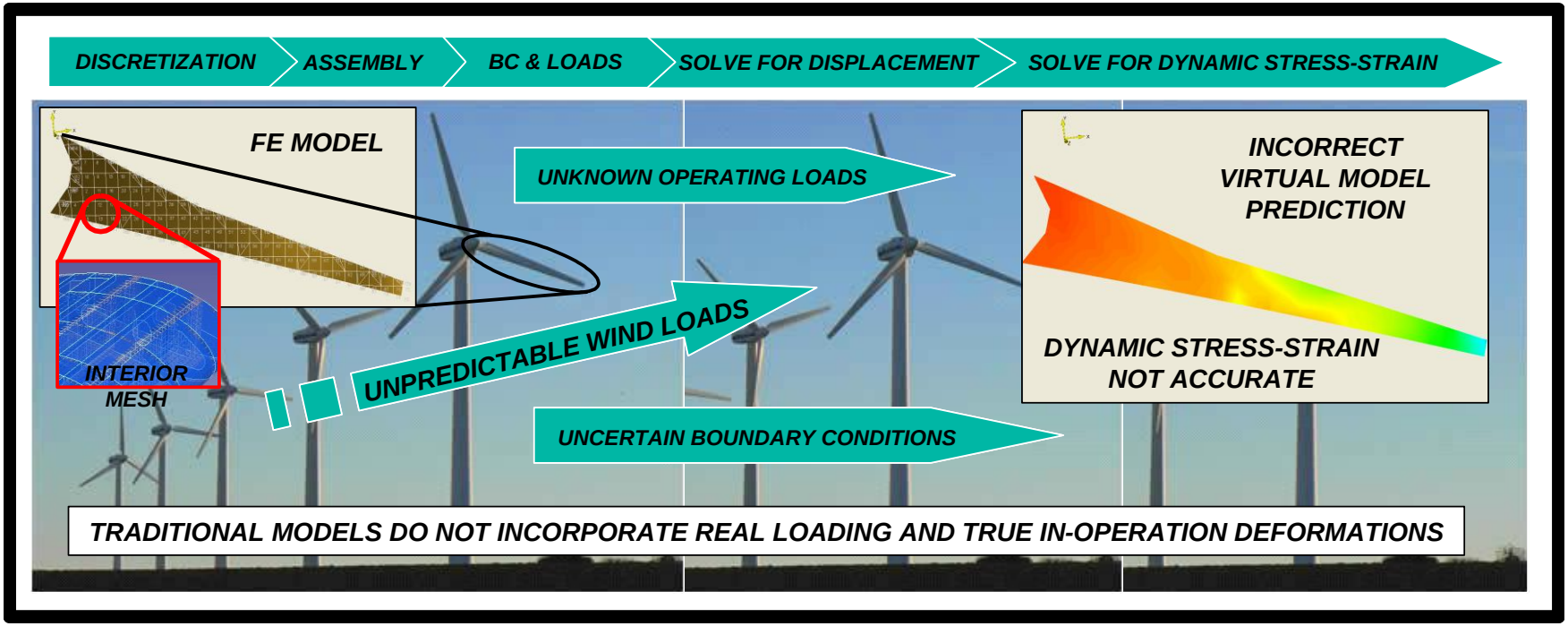
Current Methodology for Dynamic Response

Critical assumption that the loads and boundary conditions for the model are known

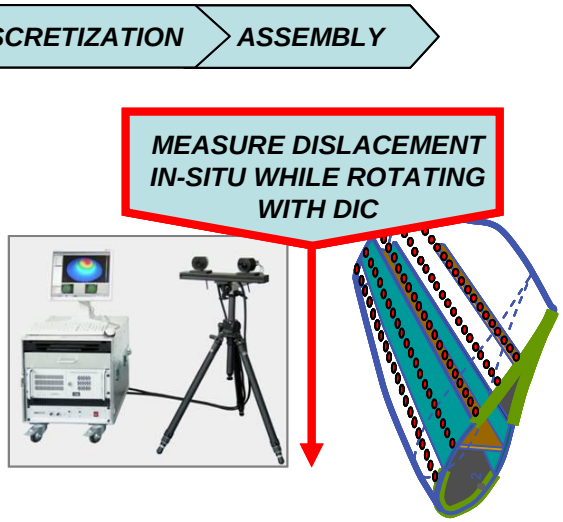


Fluid structure interaction models help predict forces but have many unsubstantiated assumptions

Fundamental Change in Approach

Develop FEA model as usual

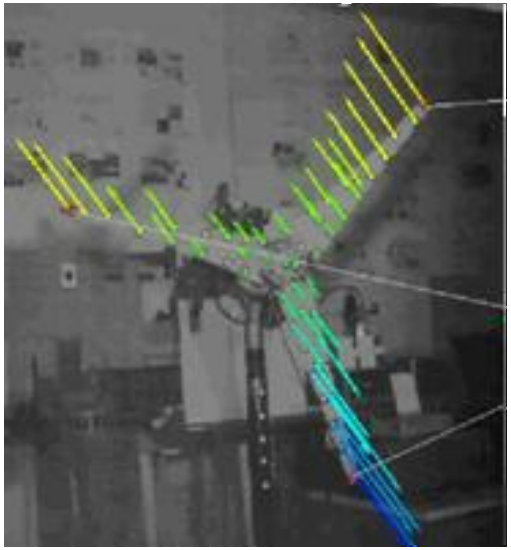
Measure response using full field approaches
- Pontos for discrete points
- Aramis for surface strain



Advantage

No assumption as to load or boundary conditions

Actual displacement directly obtained



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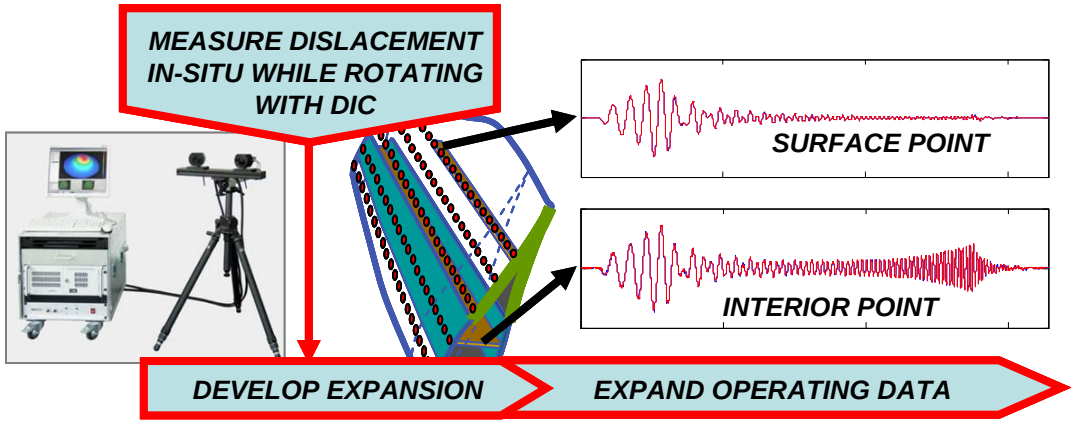
Fundamental Change in Approach

Operating (Real-time) displacements are expanded to the full set of analytical degrees of freedom in the finite element model using orthogonal shape based expansion functions.

Provides full field displacement solution



$$[T_U] = [E_n][E_a]^g \qquad [RTO_n] = [T][RTO_a]$$

Theoretical Approach – Expansion Methodology

Full-set degrees of freedom obtained from

$$\{X_n\} = [T]\{X_a\}$$

Reduced system matrices can be written as

$$[M_a] = [T]^T [M_n][T] \qquad [K_a] = [T]^T [K_n][T]$$

System Equivalent Reduction Expansion Process (SEREP) Transformation

$$[T_u] = [U_n][U_a]^g$$

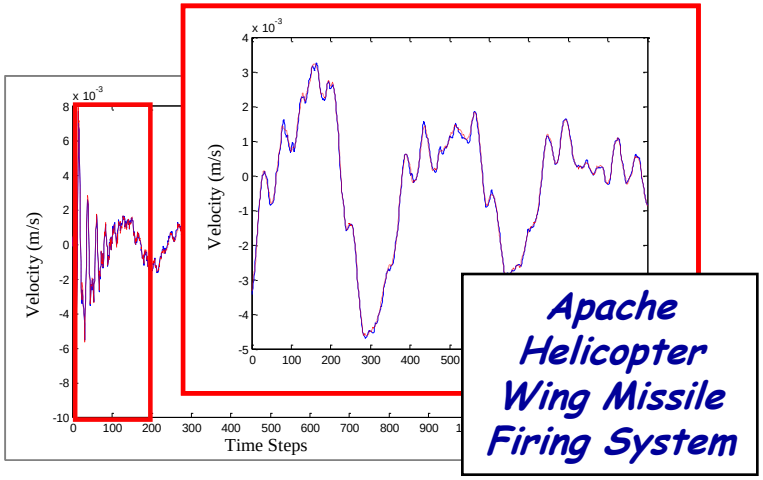
Real time operating data expanded using

$$[ERTO_n] = [T][RTO_a]$$

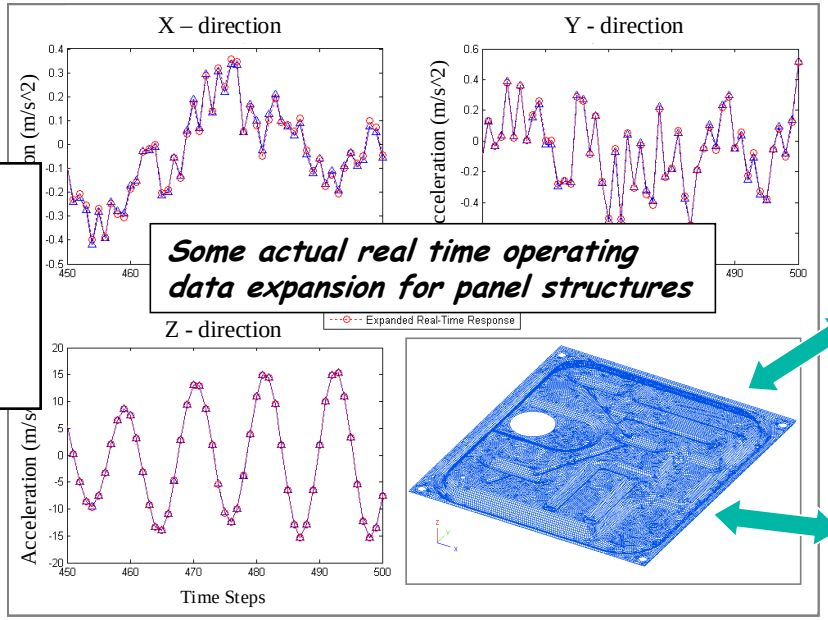
Real Time Operating Expansion

Expansion process has been demonstrated for several structures such as

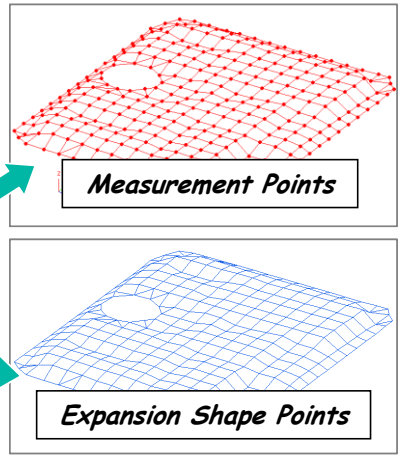
- **Apache wing**
- **dryer panel**



Whirlpool Dryer Panel Model Correlation



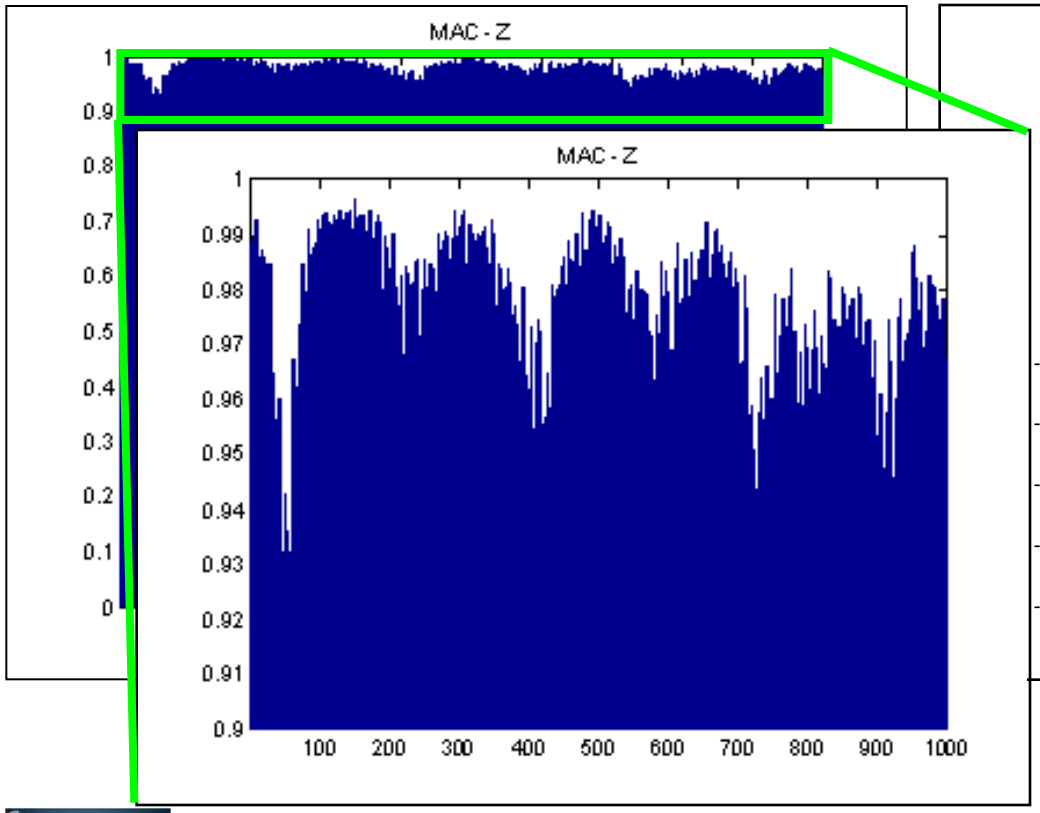
Dryer Panel Real Time Operating Data

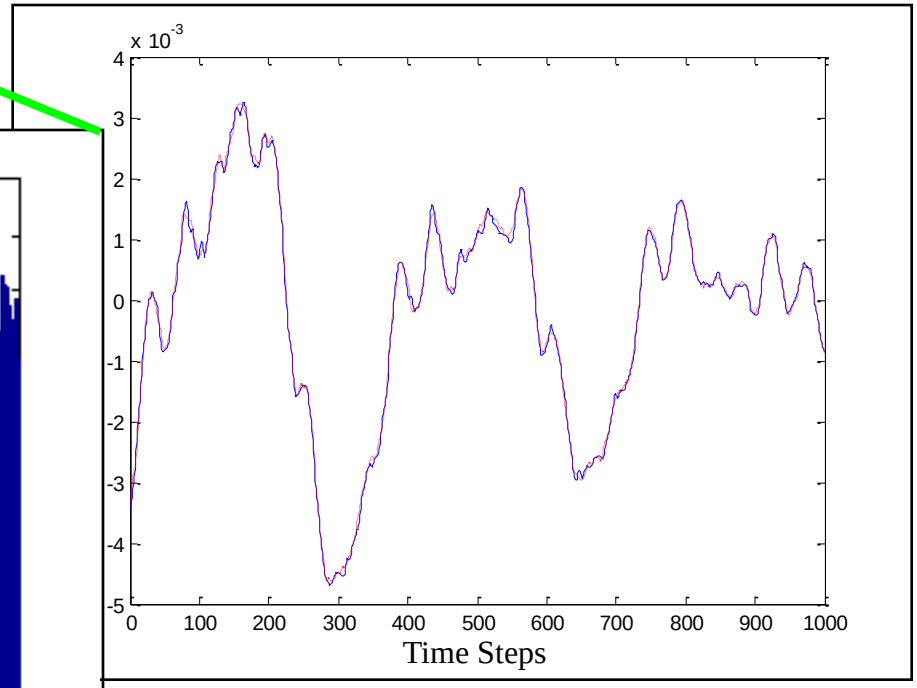


Experimental Data – Whirlpool Dryer Base

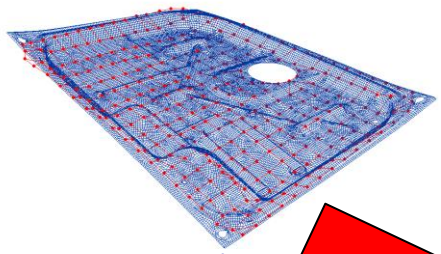
- RTO Expanded from 31 'a' set to 310 'n' set with experimental modes

$$[T_U] = [E_n][E_a]^g \qquad [RTO_n] = [T][RTO_a]$$

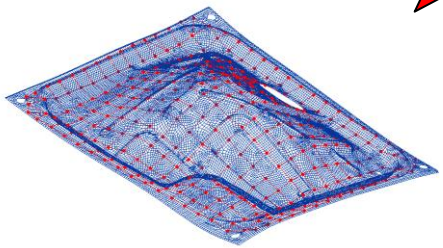




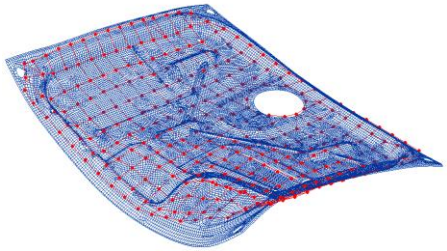
Experimental Data – Panel Structure



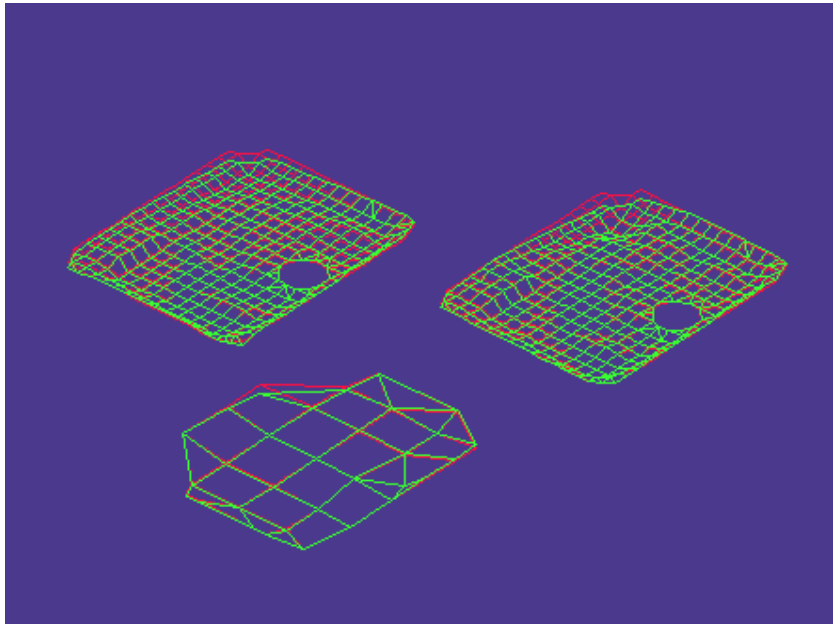
Mode 1



Mode 2



Mode 3

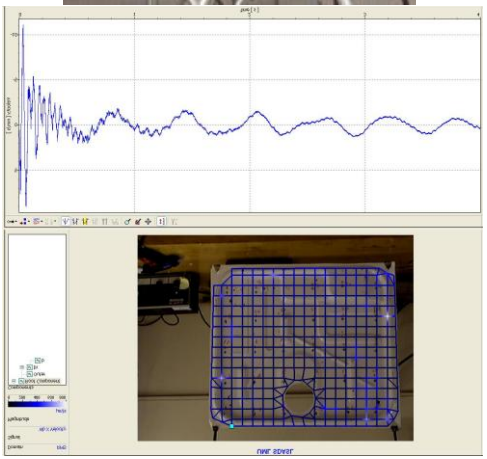


'a' set

Limited Measurement Points

$$[T_U] = [E_n][E_a]^g$$

$$[RTO_n] = [T][RTO_a]$$



RTO – Polytec Scanning Vibrometer

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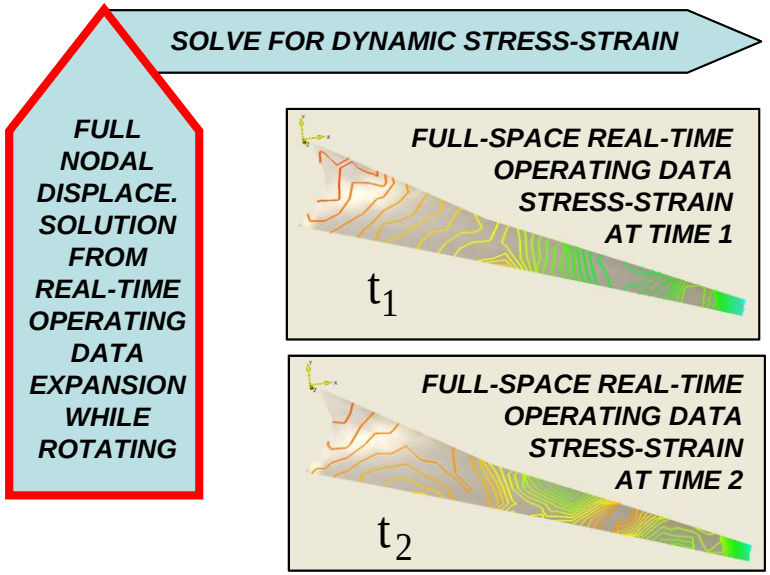
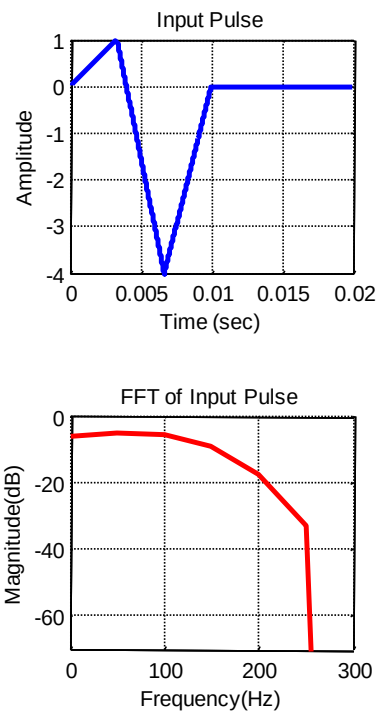
Fundamental Change in Approach

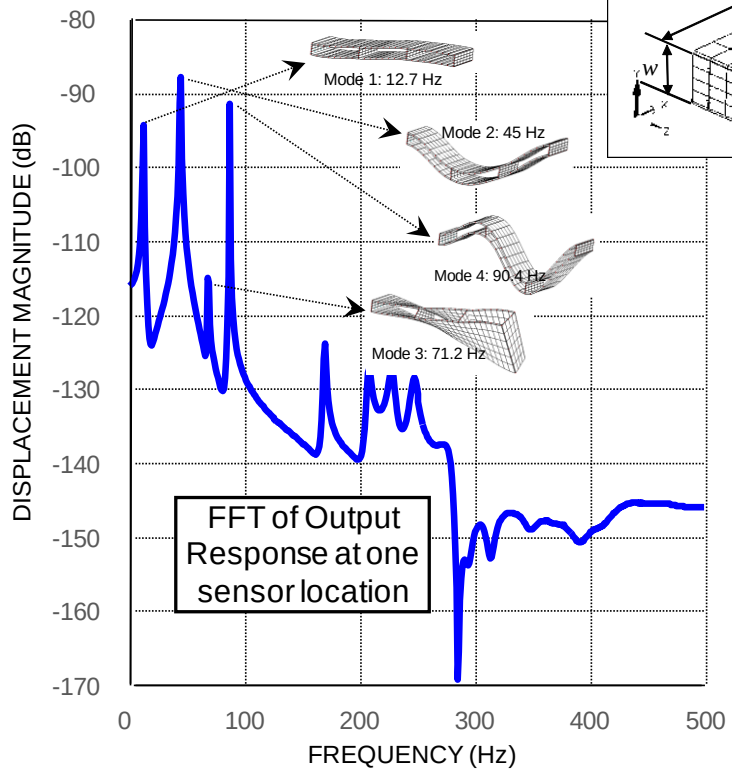
Using the real time operating data, expansion of limited sets of data will be interjected back into the finite element model to predict full field dynamic stress-strain

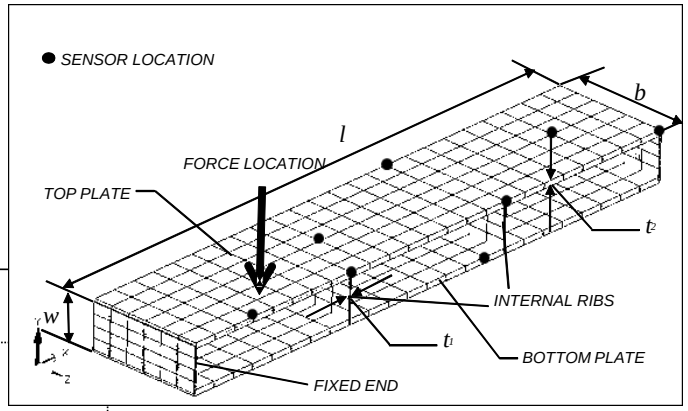


Generic Rib Stiffened Panel Structure

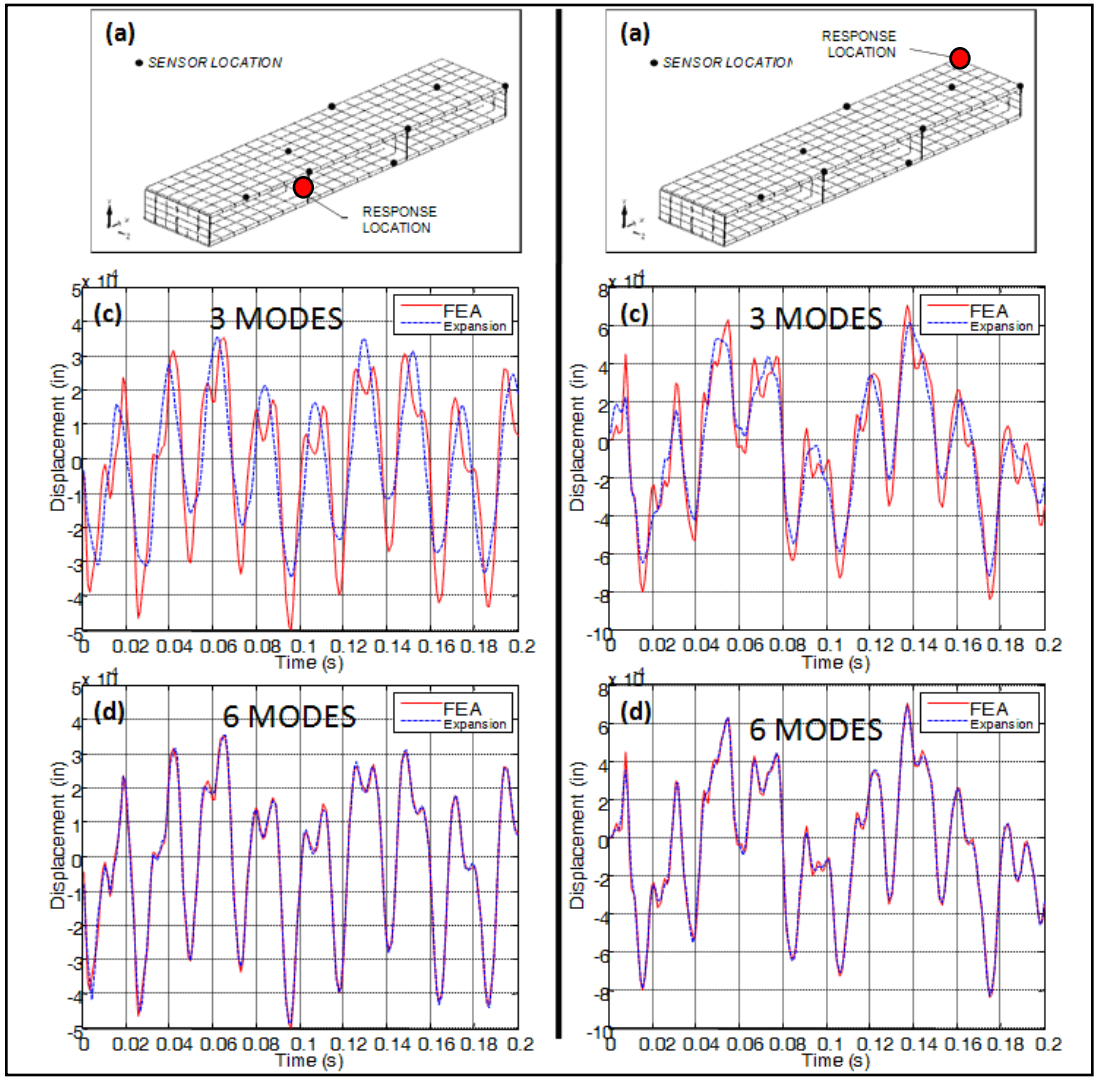
A generic model is studied to prove methodology

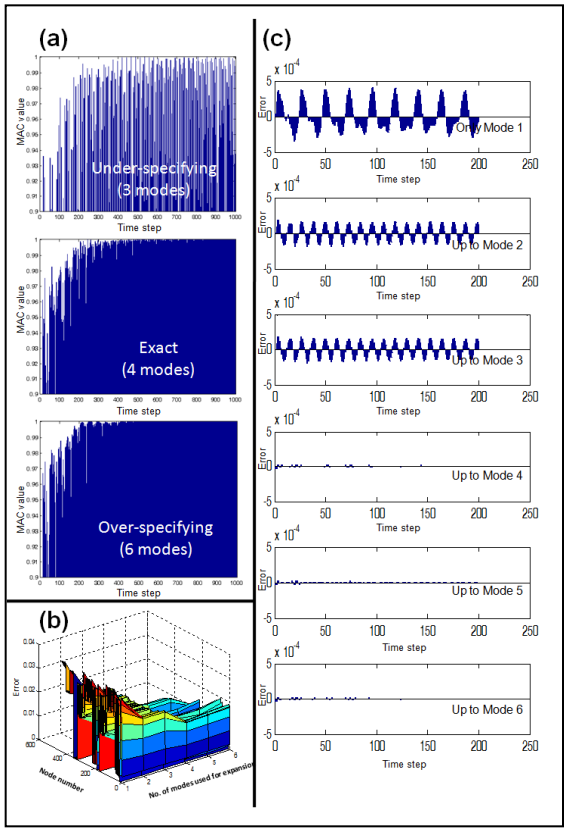






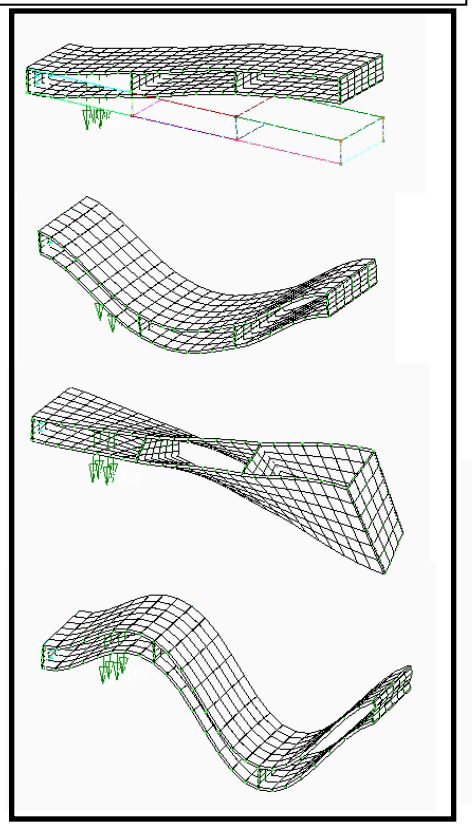
Generic Structure Expansion Results





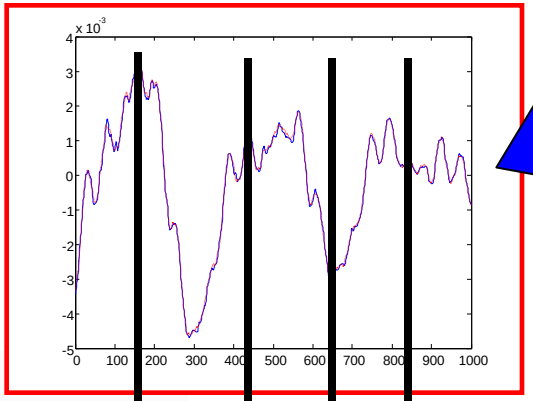
Generic Structure Dynamic Stress Expansion

MODAL CHARACTERISTICS

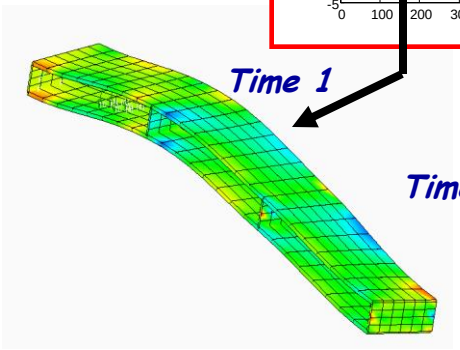


DEVELOP EXPANSION → **EXPAND OPERATING DATA**

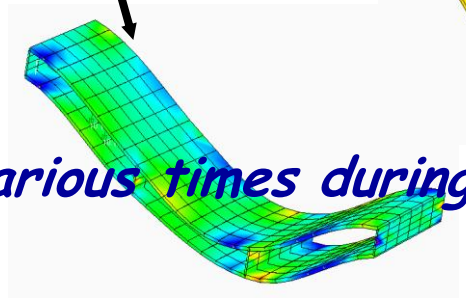
$$[T_U] = [E_n][E_a]^g \qquad [RTO_n] = [T][RTO_a]$$



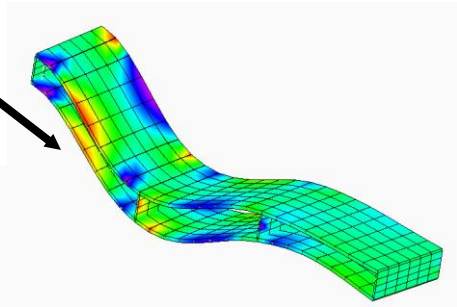
Expanded response



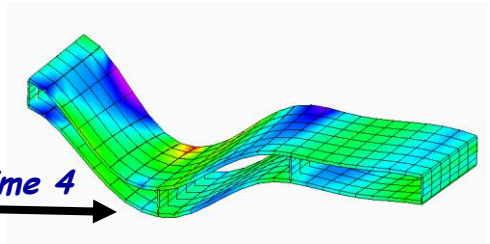
Time 1



Time 2



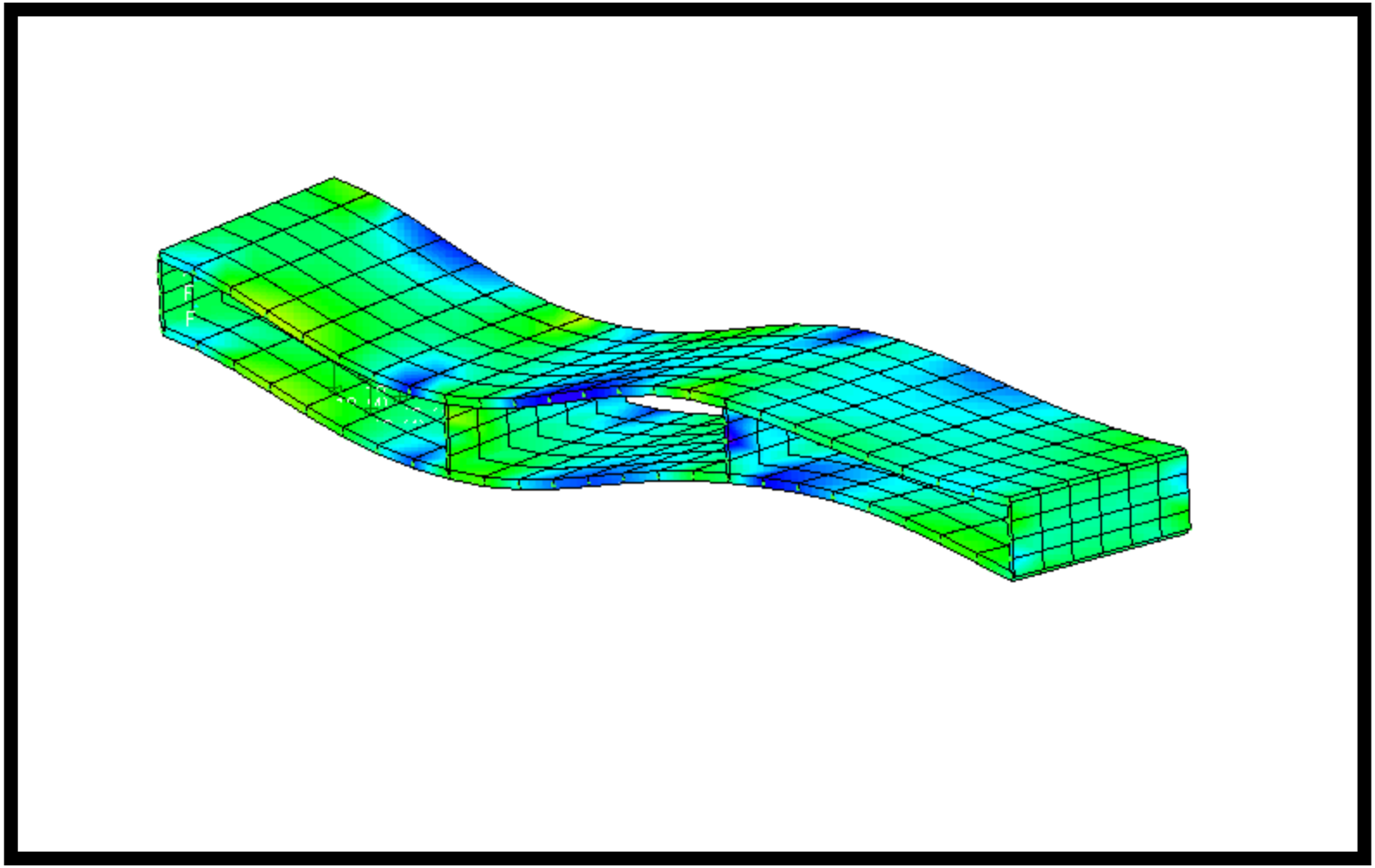
Time 3



Time 4

Dynamic stress prediction at various times during transient

Generic Structure Dynamic Stress Expansion



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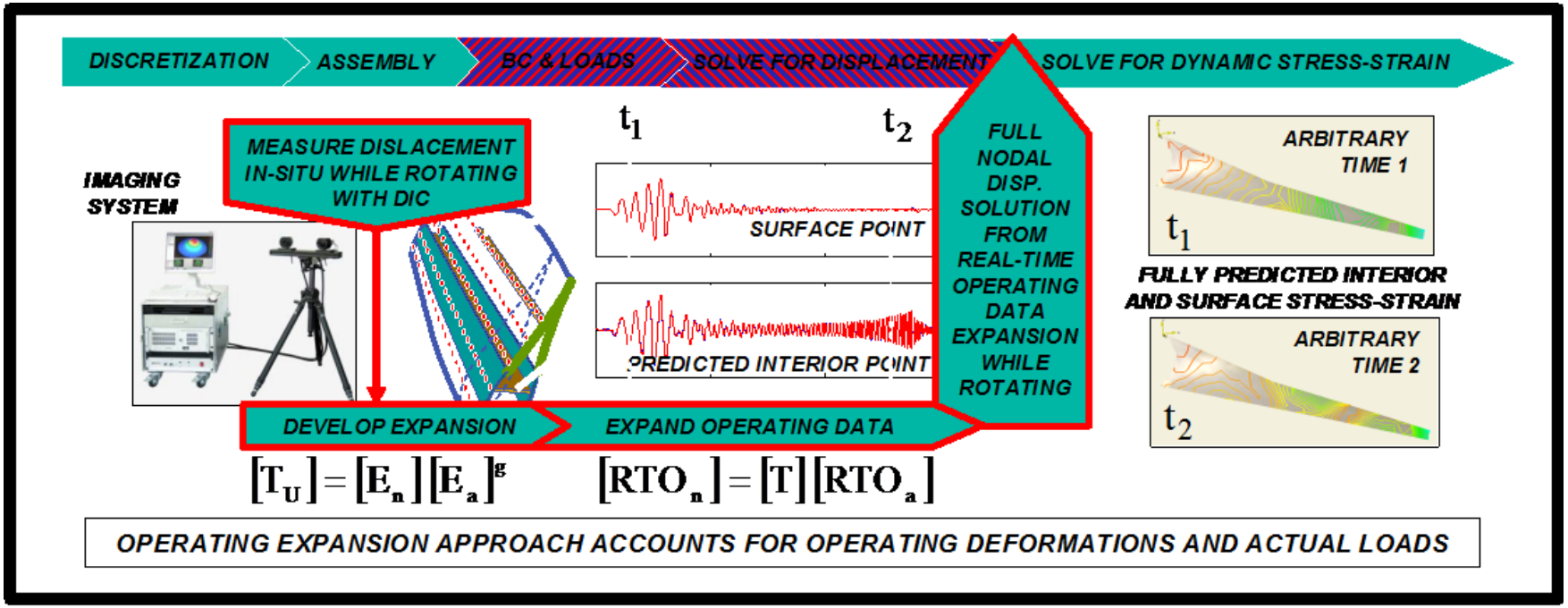
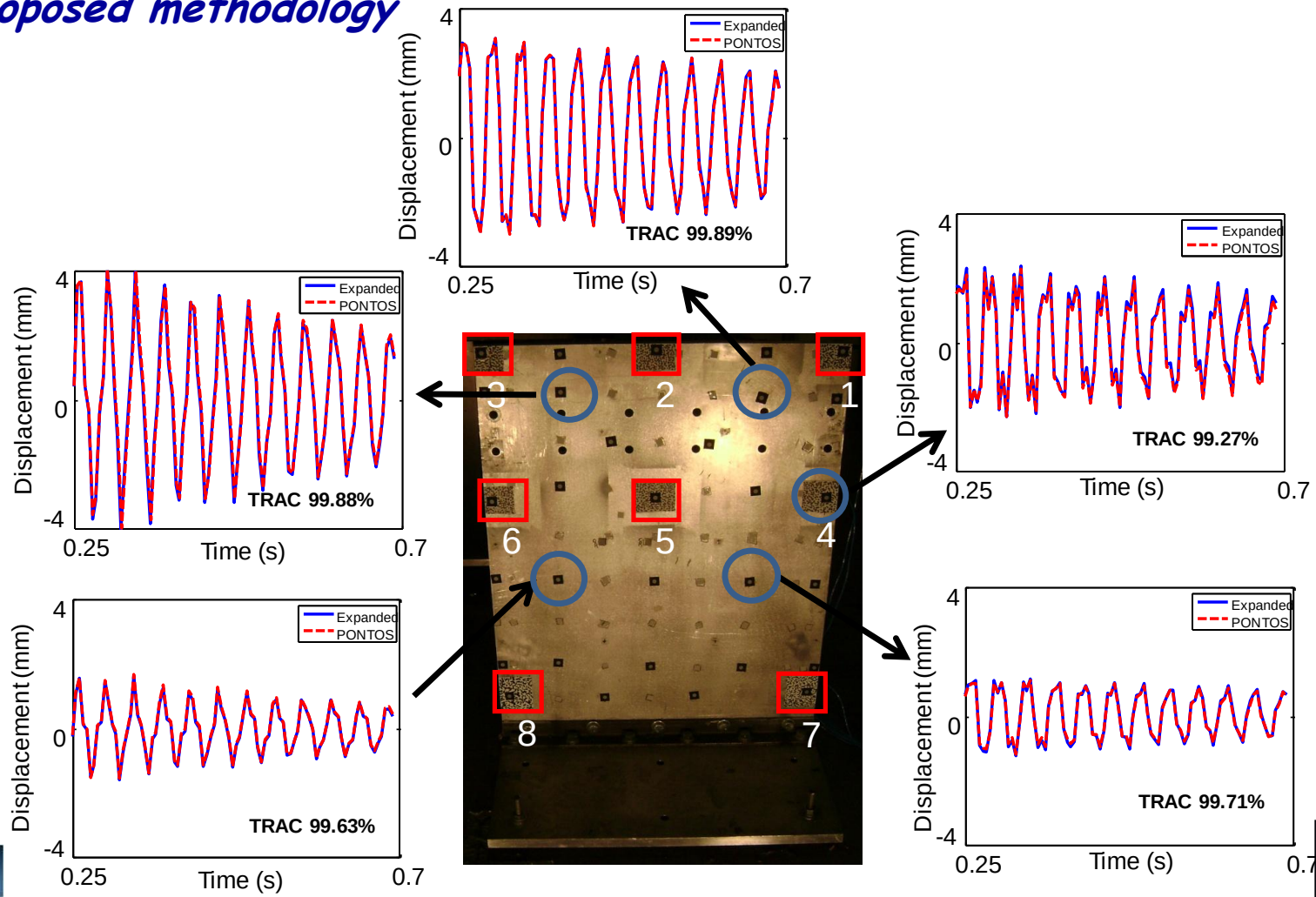
Fundamental Change in Approach

The entire process is summarized below

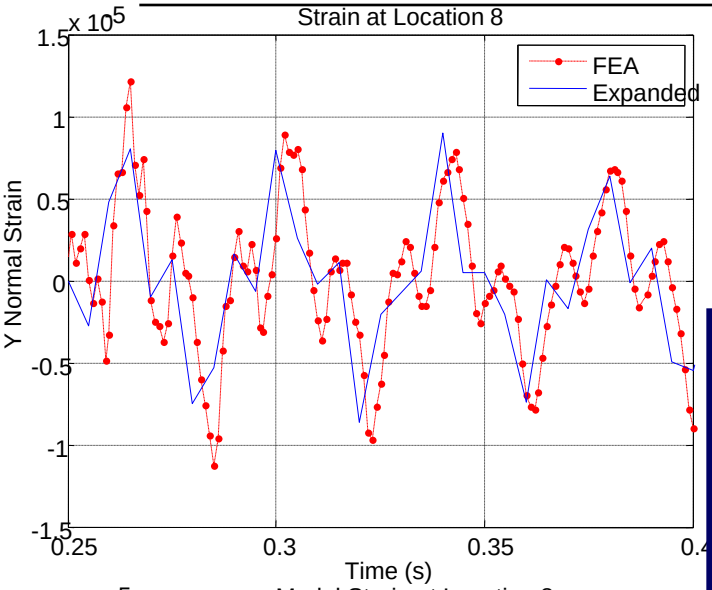


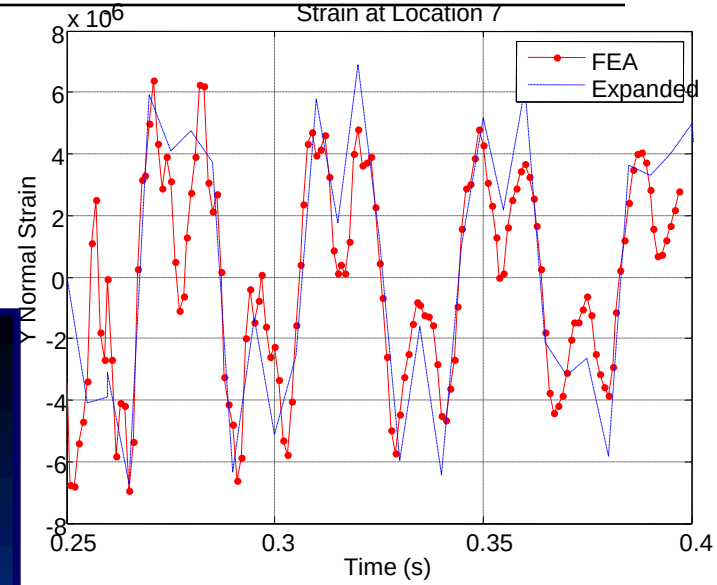
Dynamic Displacement Results – Laboratory Structure

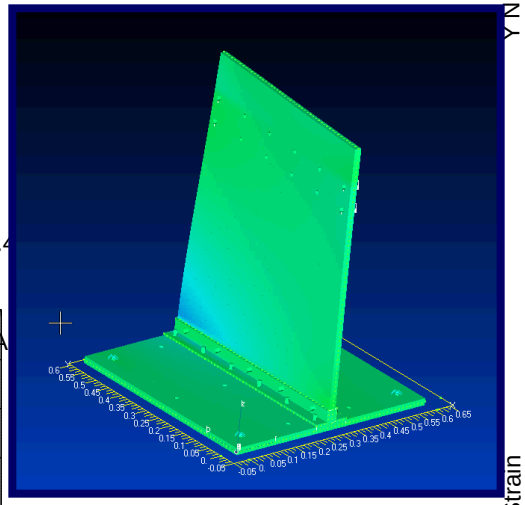
Extensive testing and analysis has been performed to validate the proposed methodology

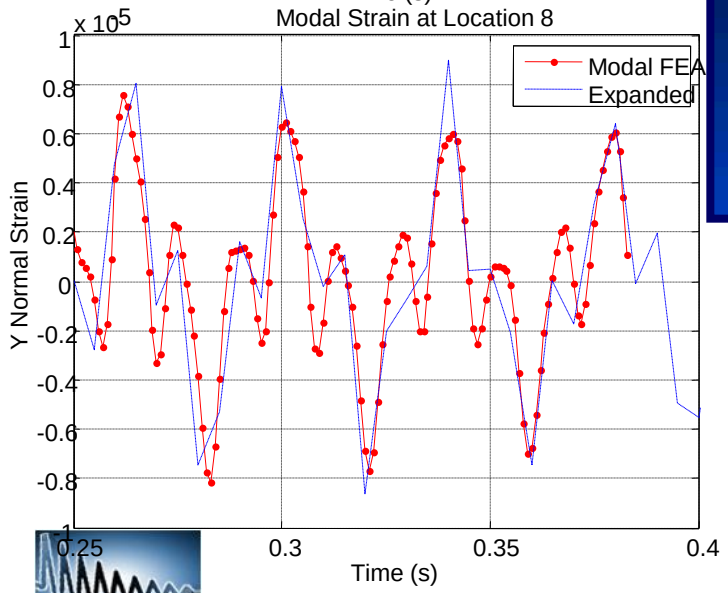


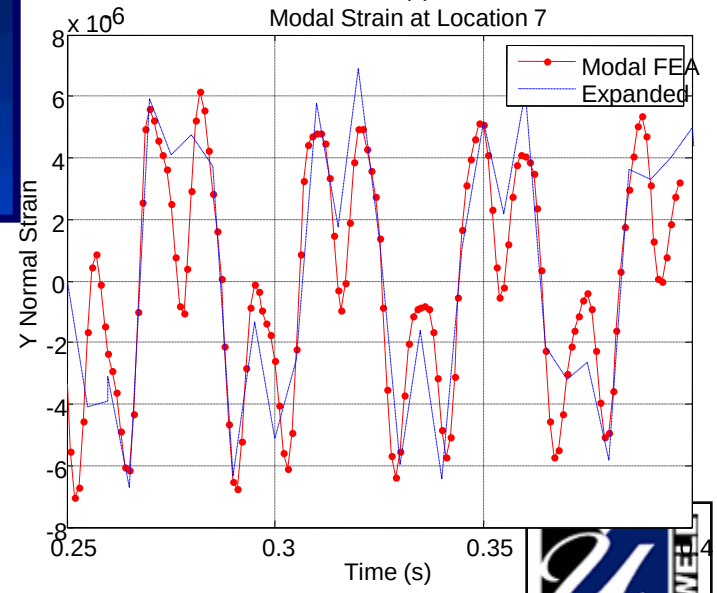
Dynamic Strain Results – Laboratory Structure











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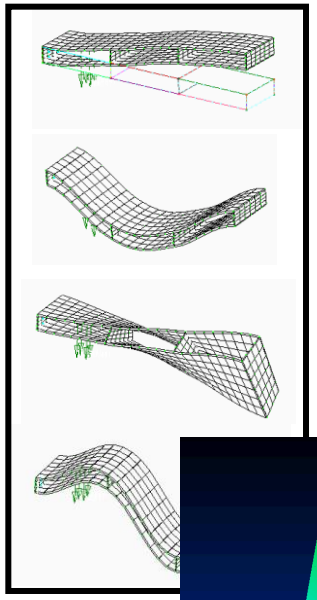
Validation of Methodology – Laboratory Structure

Prediction of Full Field Dynamic Stress/Strain from Limited Sets of Measured Data



DEVELOP EXPANSION → **EXPAND OPERATING DATA**

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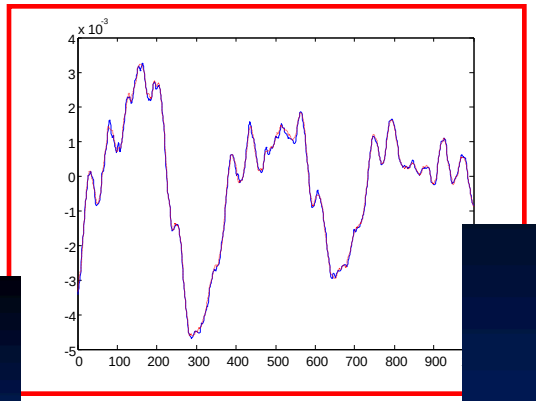
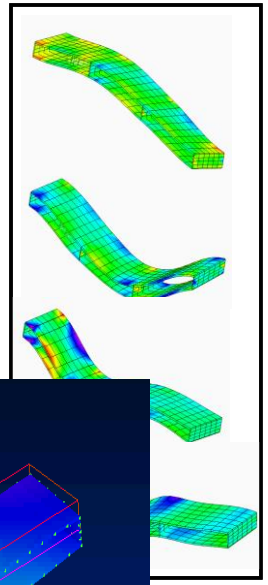
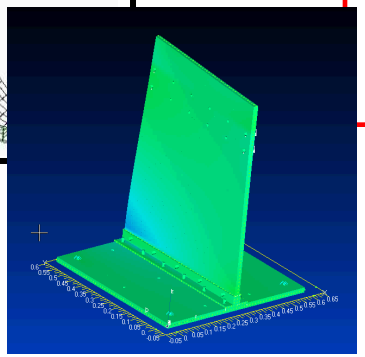
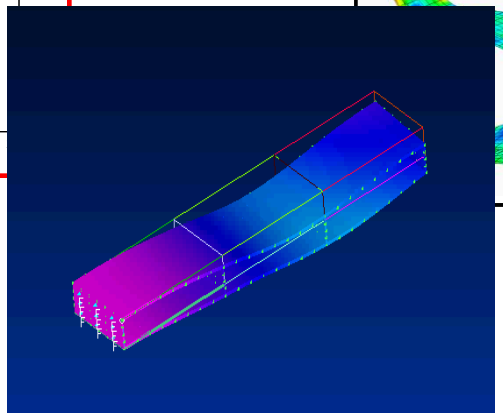


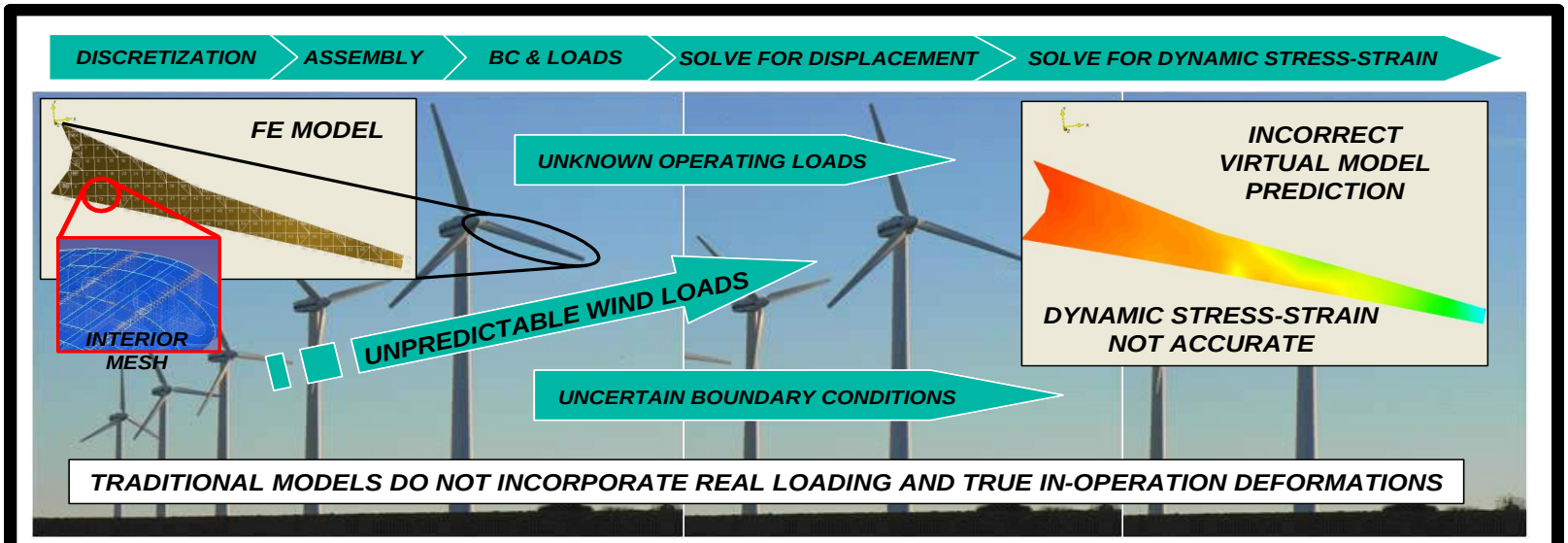


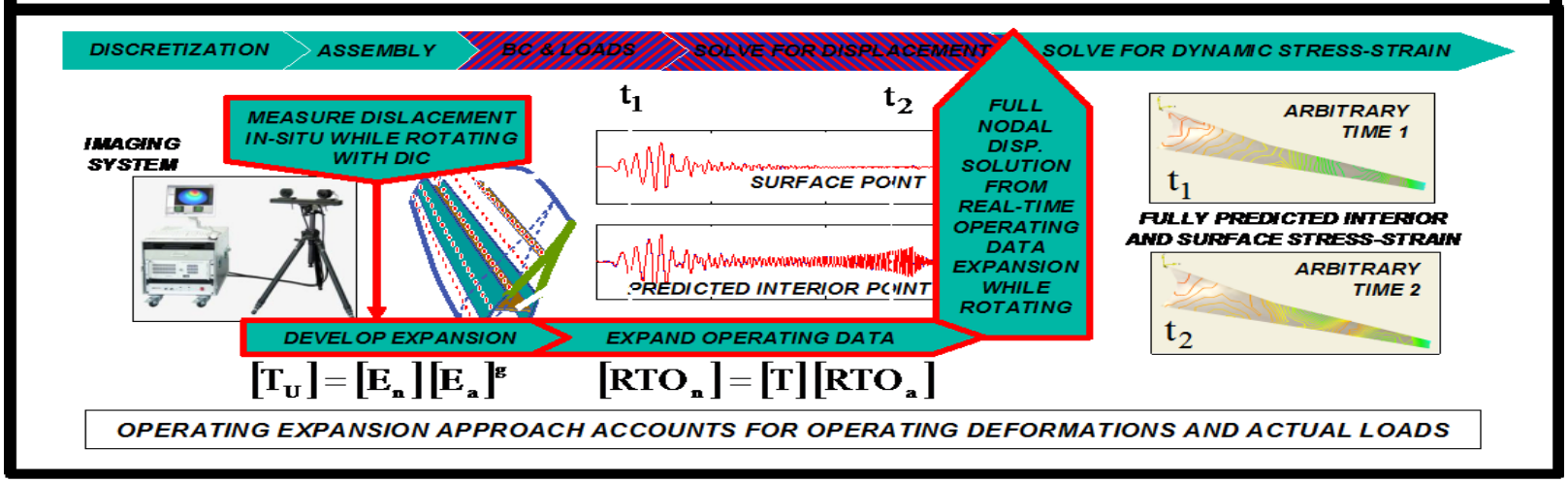




Pawan Pingle

Conventional Approach vs. Alternate Approach



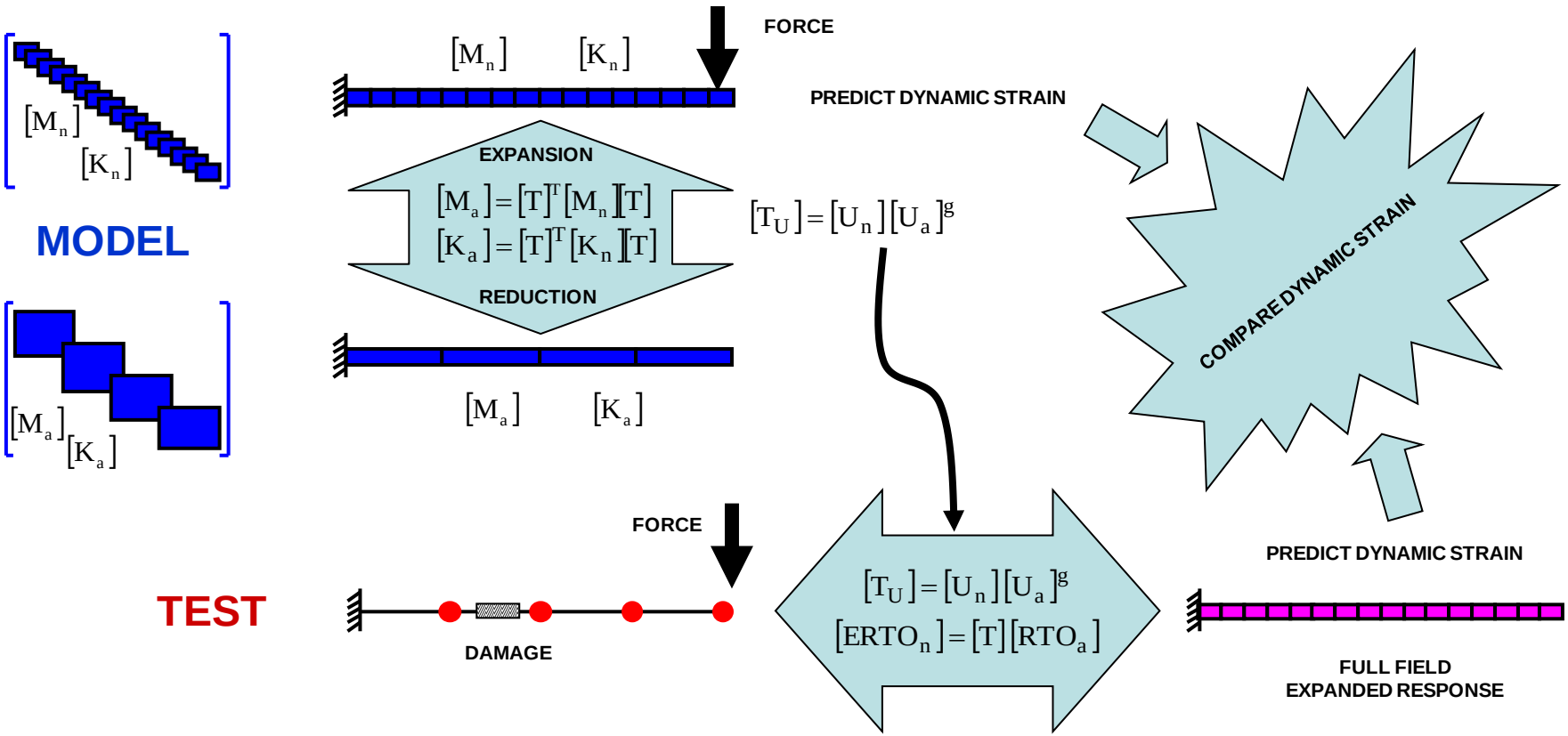


Advantages of Alternate Approach

- Loading assumptions are gone
- Actual boundary conditions are included
- Displacement of actual operation is obtained
- Operating data is expanded directly without the approximate estimate of force from limited data
- Dynamic stress-strain obtained for full field

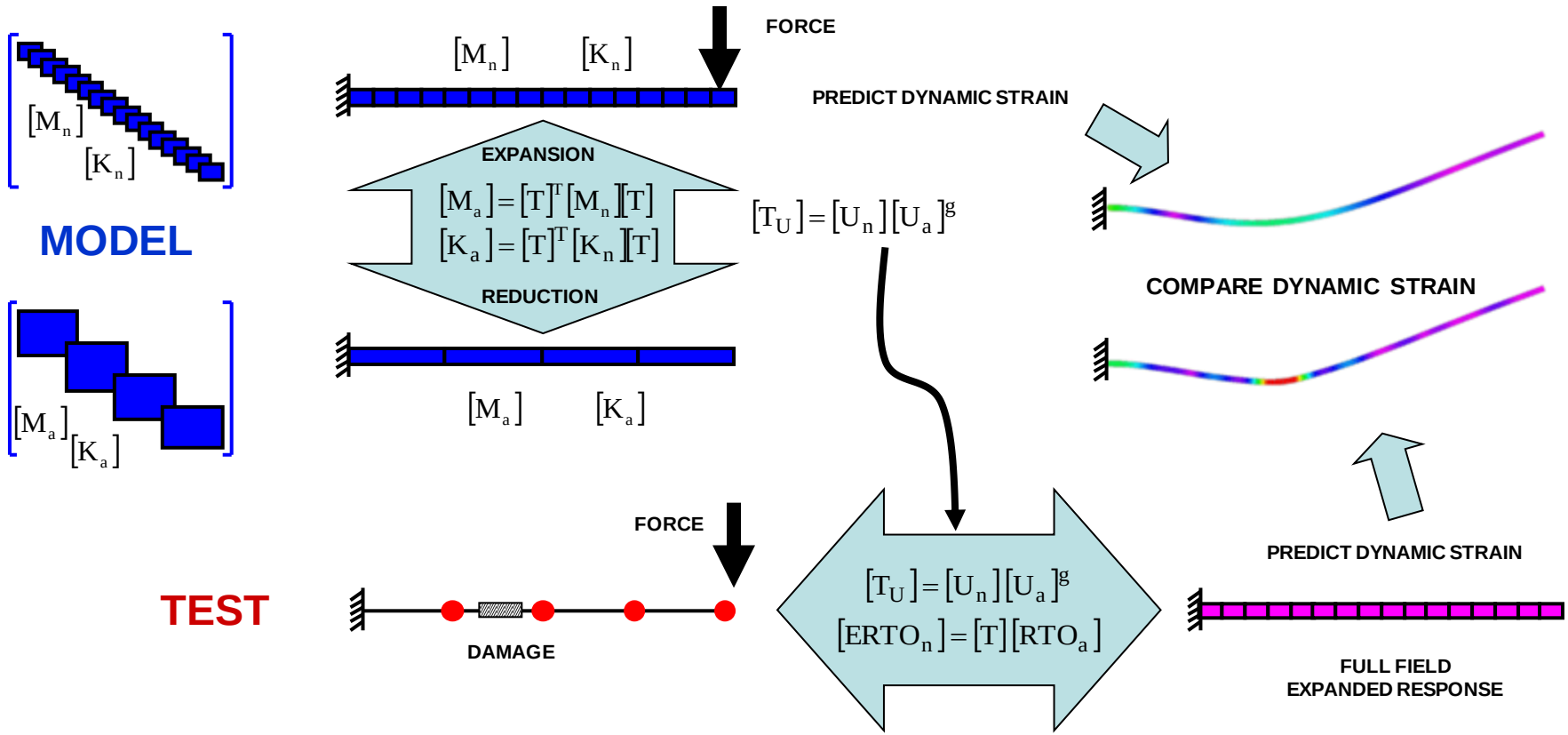
Damage Detection using Full Field Stress Strain

- Model used for expansion with measured damage at limited set of measurement points in operation



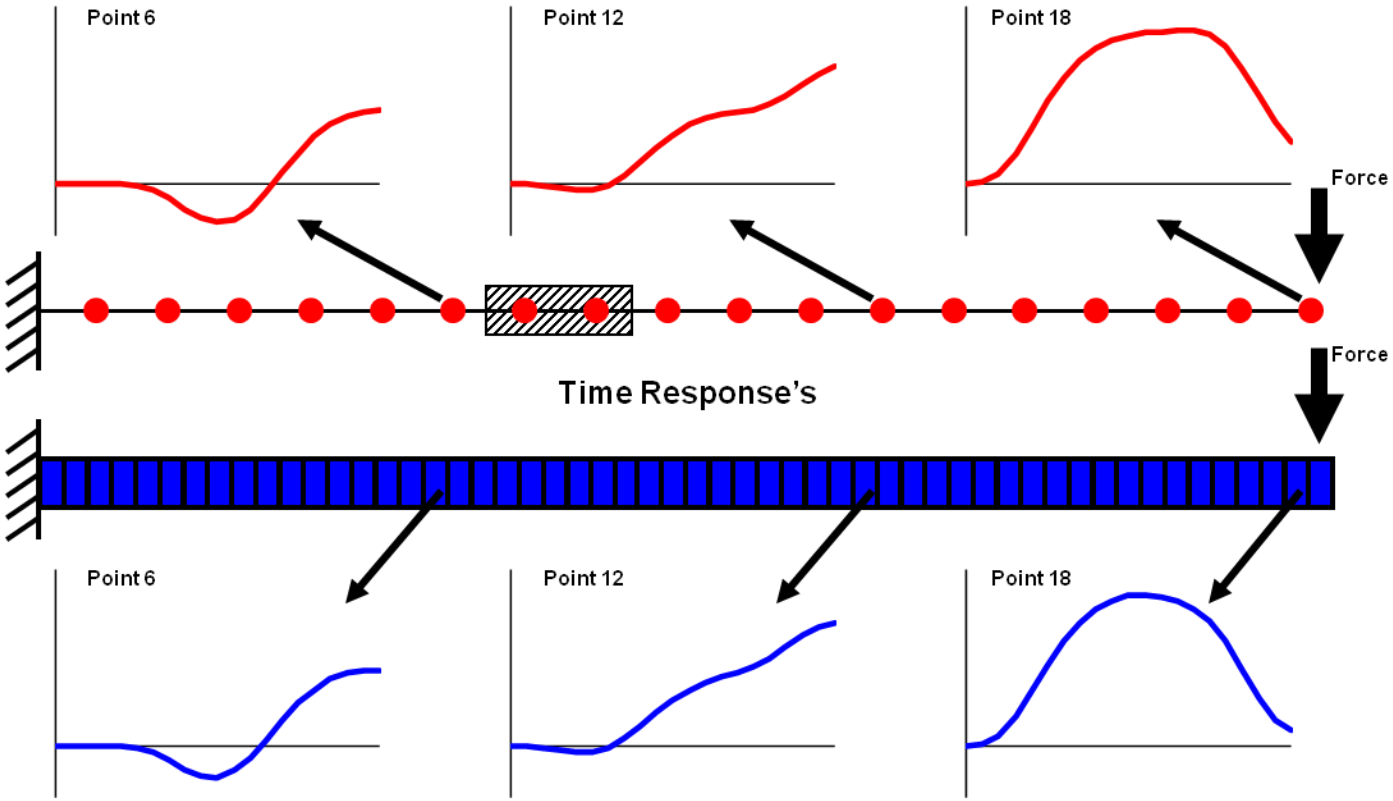
Damage Detection using Full Field Stress Strain

- Redistribution of load and strain indicate damage



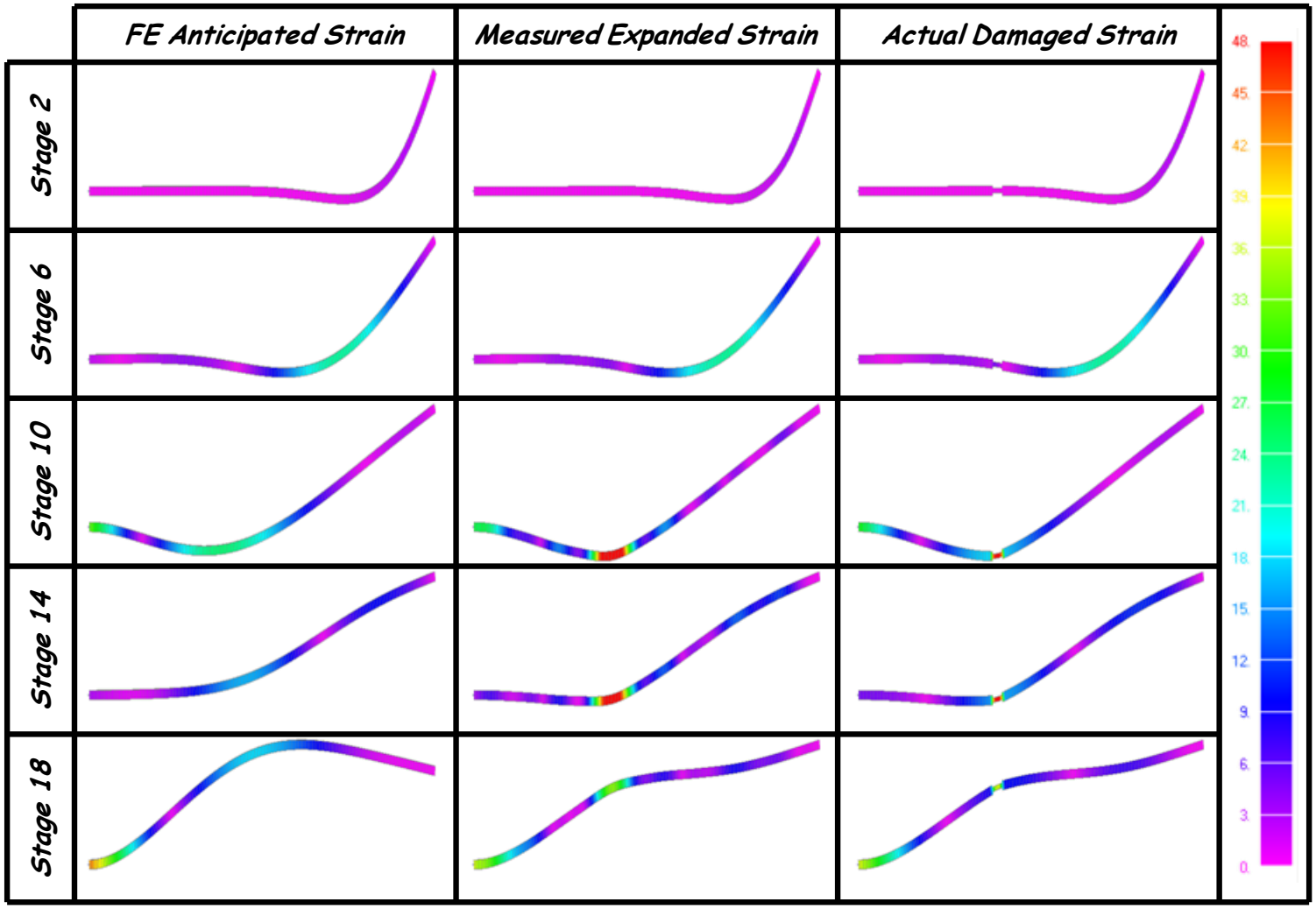
Damage Detection using Full Field Stress Strain

- Response change is not noticeable but curvature and strain due to multimode response can be seen



Damage Detection using Full Field Stress Strain

- FEA prediction, expansion and actual strain field



Damage Detection using Full Field Stress Strain

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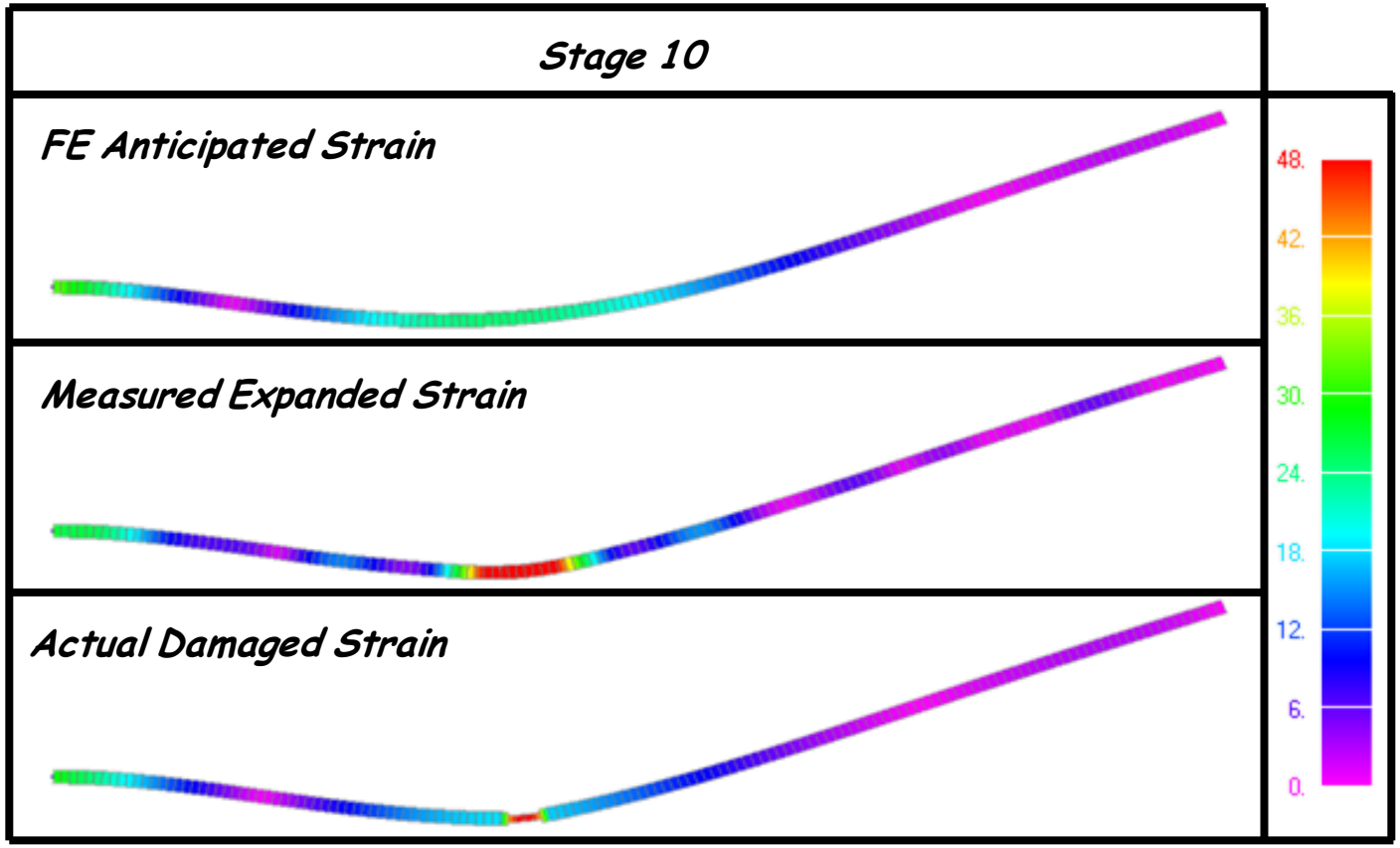
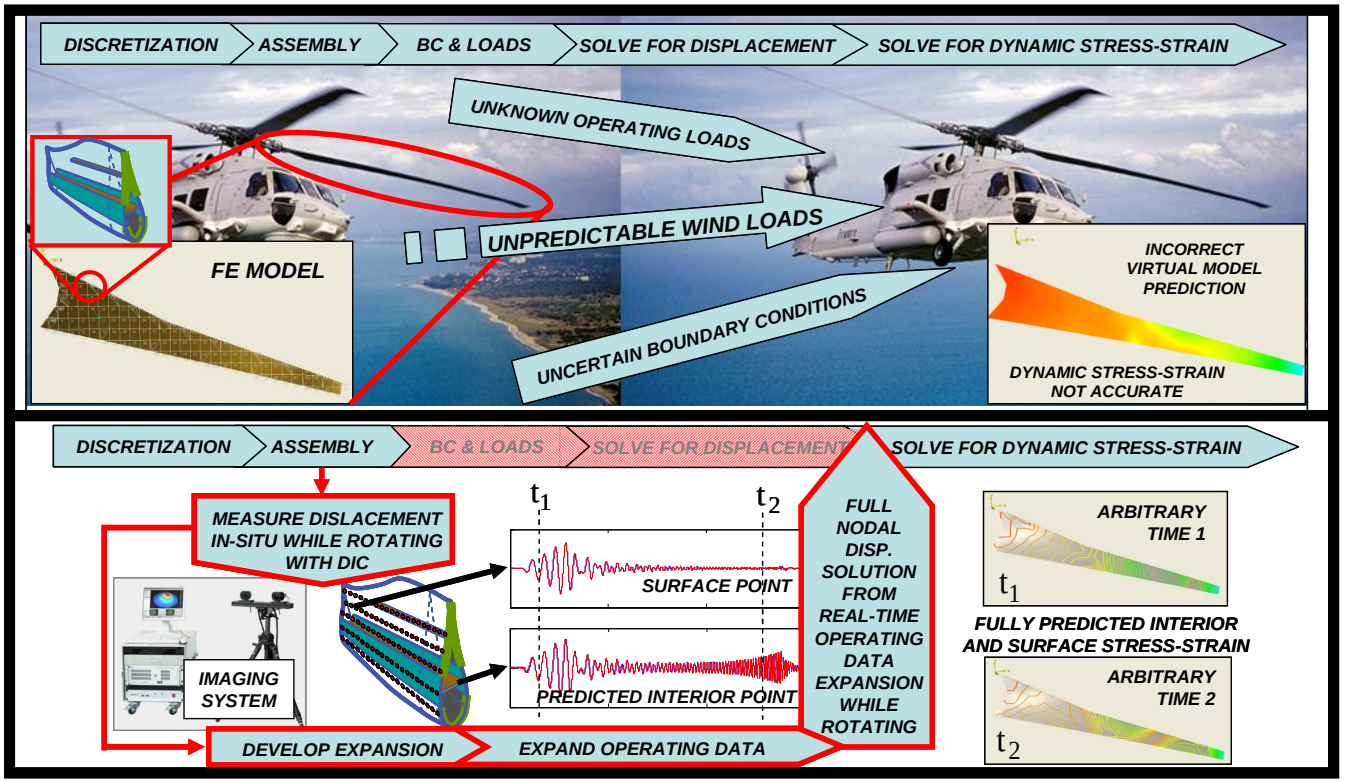


Current Methodology for Dynamic Stress-Strain Prediction for Structural Health Monitoring and System Load Prediction



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