

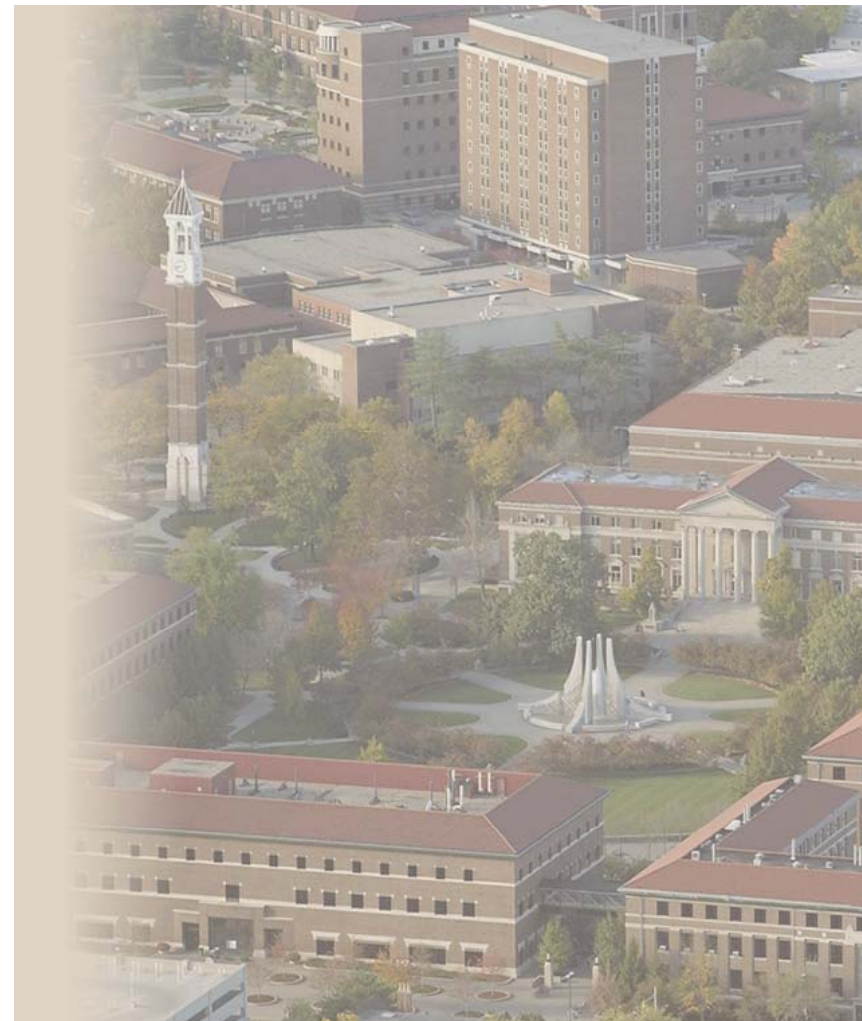
Some Technical Barriers and Point Solutions to Realizing CBM

November 29, 2007

CBM Workshop
TARDEC

Douglas E. Adams

PURDUE
UNIVERSITY



Some Numbers...

In 2006, 161 exabytes (billion GB) were generated.

In 2010, 988 exabytes (billion GB) will be generated.

Amount of digital data in the world doubles ~ 11 min.

5.1 sec of data for three sensor channels at 200 Hz:

15 KB per dataset.

254 MB per day.

92.5 GB per year.

Using **model-based methods** to design measurement systems and extract meaningful features for usage monitoring, fault identification, and trending is probably essential – **the dynamics are coupled!**

Mechanical Components

Examples of condition monitoring applications with commonality



Composite missile



Blades & fuselage



Susp/frame ground vehicle



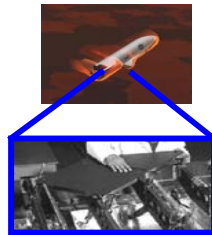
Leak detection



Tire crack detection



Wire harness diagnostics



TPS



C130J fuselage



Composite armor



Gas turbine engines



Aircraft rivet quality



Gen set valve fatigue



Fuel tanks



Spar

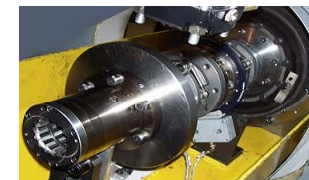


Wheel end

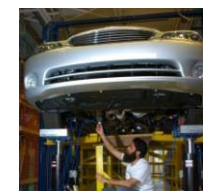
DEFENSE
CIVILIAN



Rotors & gear boxes



Drivelines



Suspensions

Issues:

Data deficit in platform

Constraints on weight, etc.

Accessibility of component

Variability in loading

Incipient damage

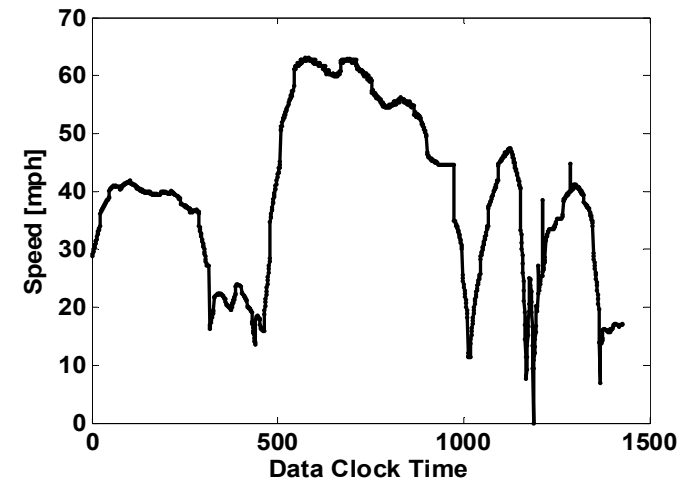
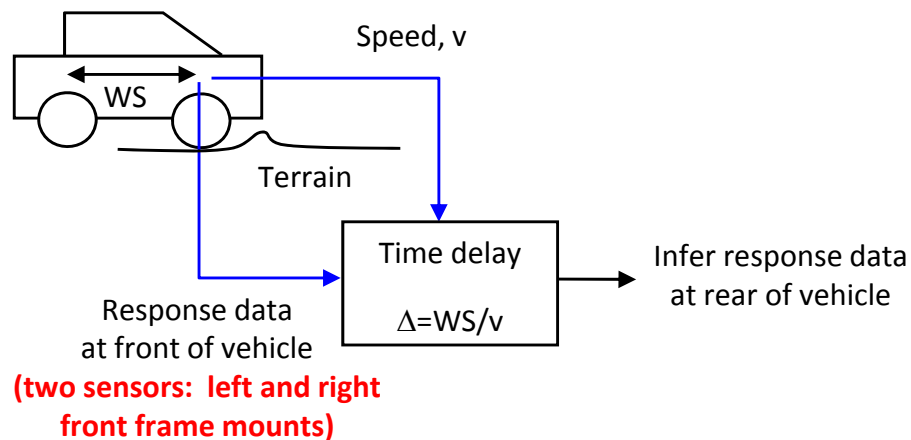
Wide area inspection

Complexity

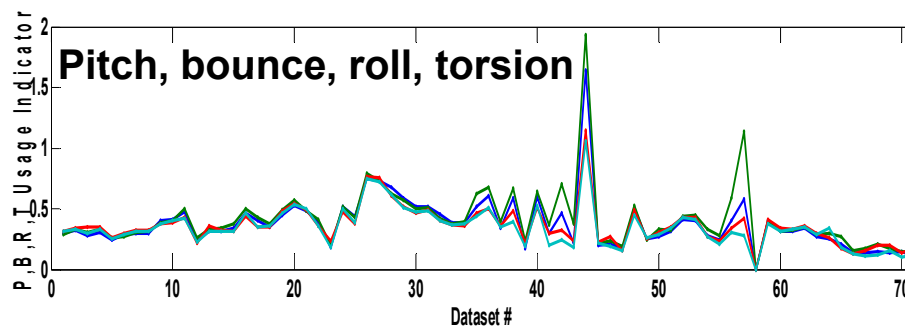
Load Identification

Lack of Data Available in Certain Platforms

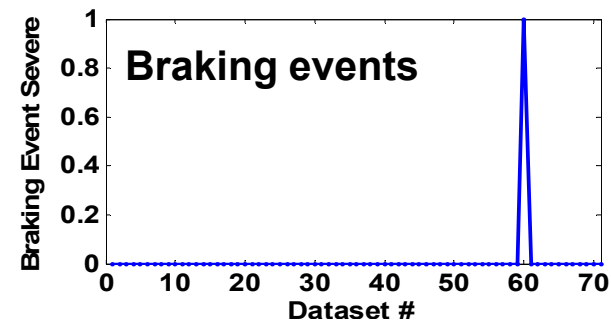
- HMMWV usage monitoring:
 - Research on: minimal sensor suites, estimation of usage.



Usage metric algorithm



Speed from laser tach



Issues:

Data deficit in platform

Constraints on weight, etc.

Accessibility of component

Variability in loading

Incipient damage

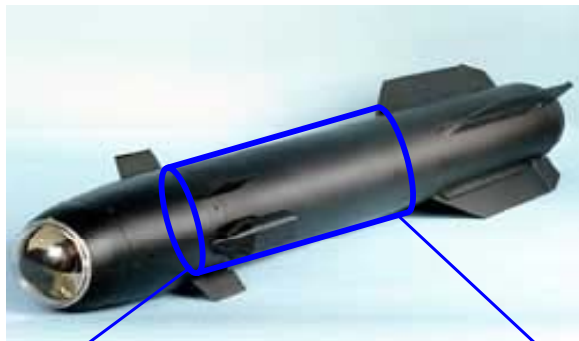
Wide area inspection

Complexity

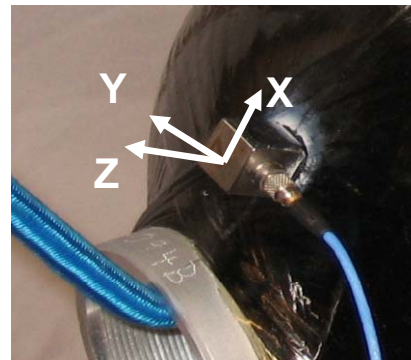
Load Identification II

Constraints on Weight and Power

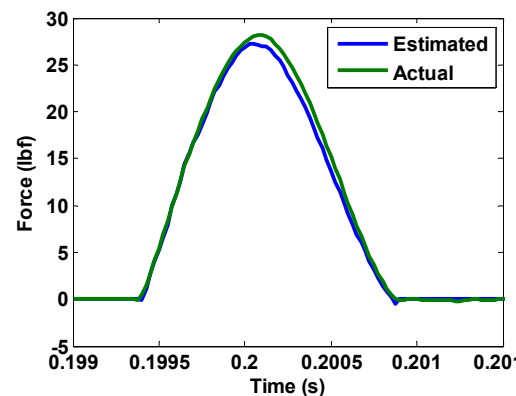
- Carbon filament wound missile casing (light for precision):
 - Research on: inverse problems, model updating upon impact.



**Carbon fiber
missile casing**



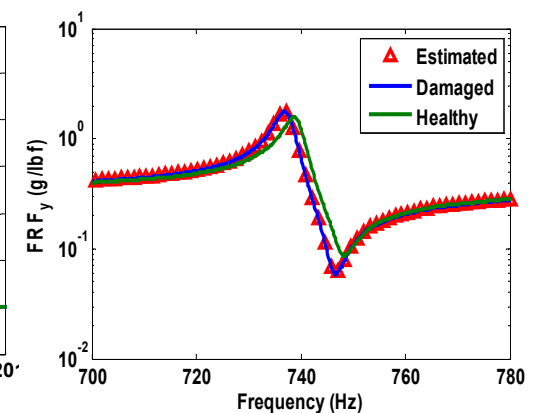
3-axis sensor



Force estimate



10 ft-lb impact



Updated model

Issues:

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Incipient damage

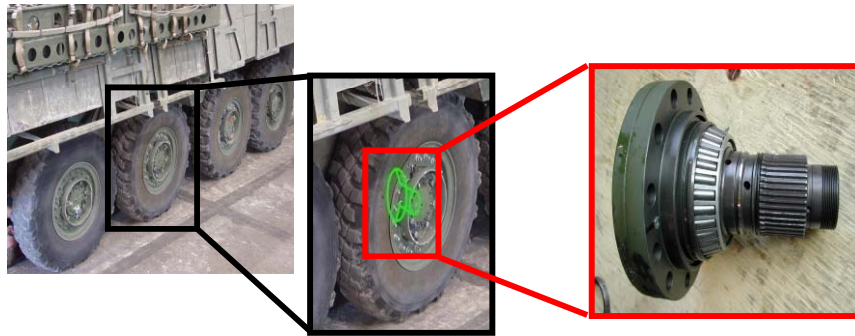
Wide area inspection

Complexity

Damage Identification

Detection of Damage in Non-Accessible Component

- Metal spindle housed in wheel assembly (up armor loading):
 - Research on: repeatability of attachment, outlier analysis.



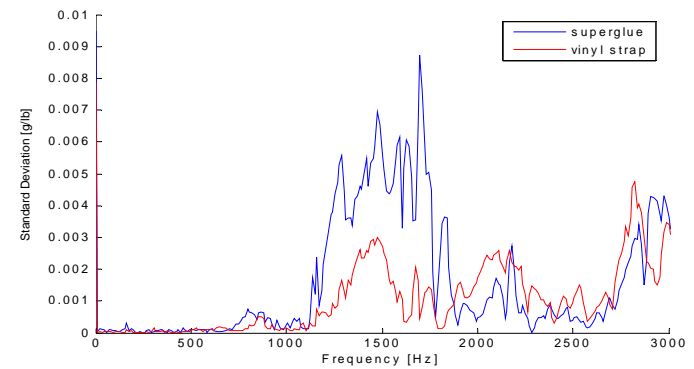
Spindle inside wheel assembly



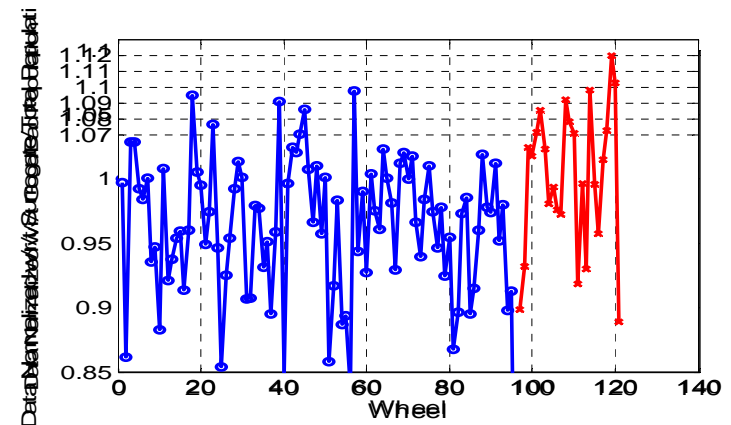
Test on vehicle



Test instrument



Variability in attachment



Outlier detection

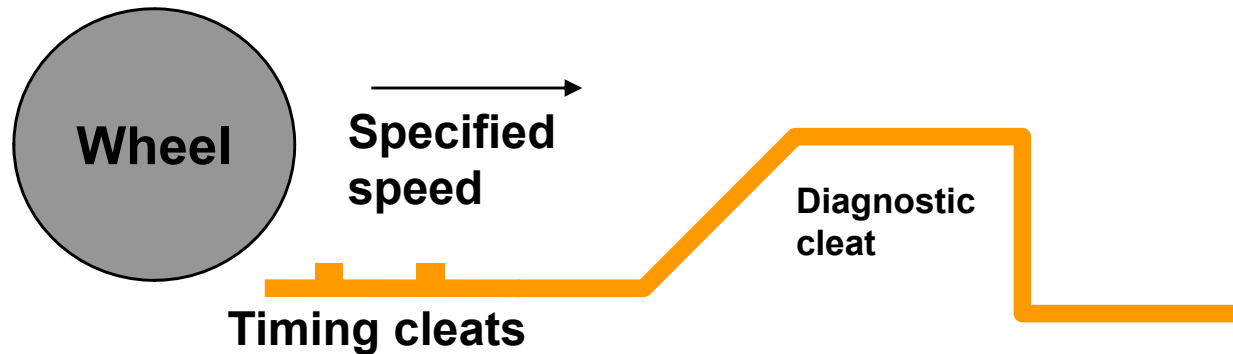
Issues:

Data deficit in platform
Constraints on weight, etc.
Accessibility of component
Variability in loading
Incipient damage
Wide area inspection
Complexity

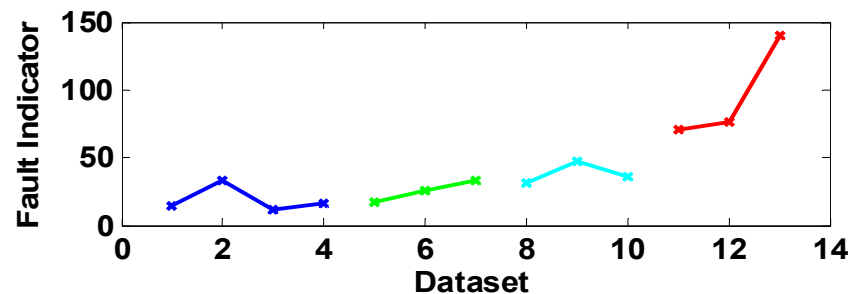
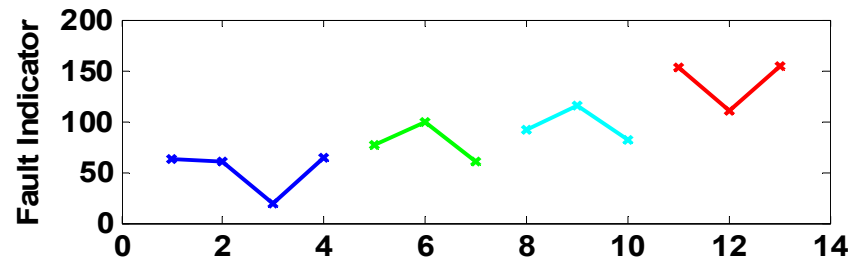
Damage Identification II

Operational Variability in Usage Environment

- Truck suspension fault in sway bar link (HMMWV tie bolt):
 - Research on: portable cleats for NDT, semi-active detection.



RF Control Arm, RF Frame



Issues:

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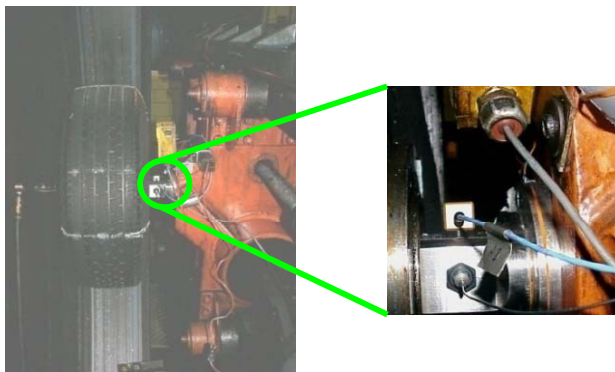
Damage Identification III

Need for High Sensitivity Fault Indices to Detect Incipient Faults

- Rolling tire with bead area damage (wheeled vehicles):
 - Research on: data fusion using coupling, modeling of tire.



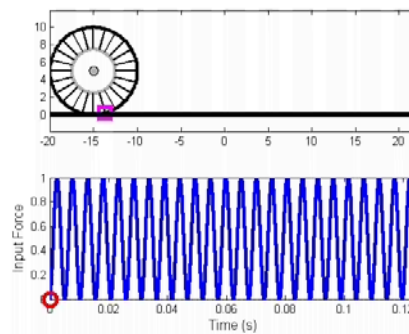
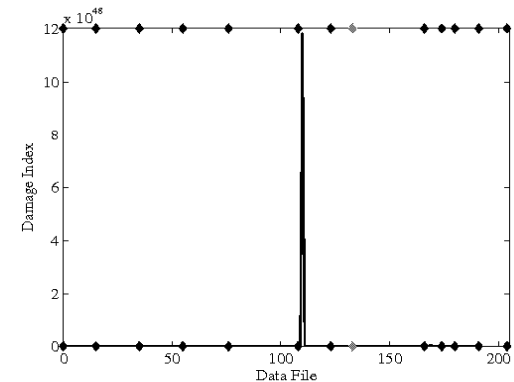
Crack and Bulge



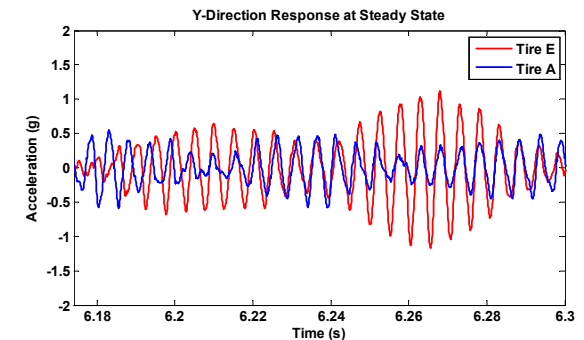
Durability Test

$$\sum_{x,y,z} A, \prod_{x,y,z} A$$

Algorithm and Fault Index



Model and Simulation (240 Hz)



Issues:

Data deficit in platform
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Incipient damage
Wide area inspection
Complexity

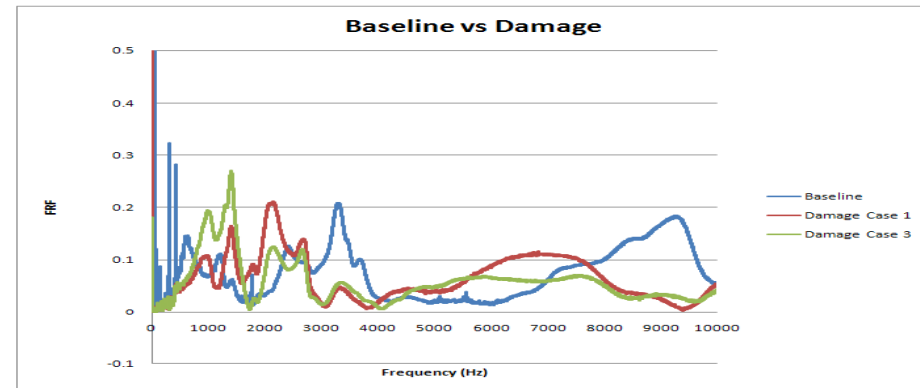
Damage Identification IV

Methods for Damage Identification in Large Component

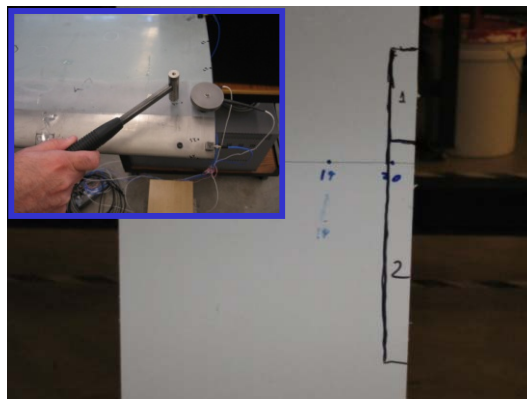
- Heavy lift helicopter composite structure (supportability)
 - Research on: wide area detection, simulated delamination.



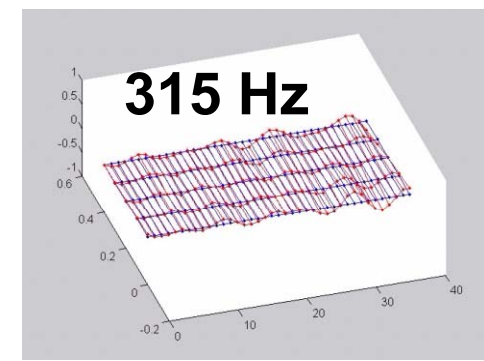
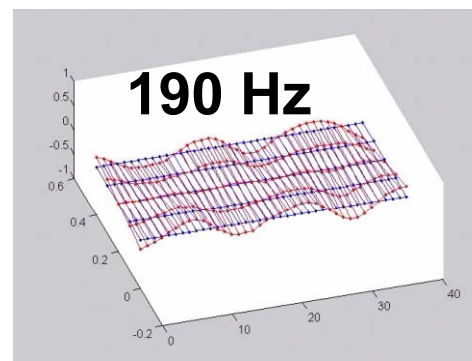
Heavy lift helicopter



Modal Hammer Measurement at Root



Sensing and Delamination



Full-Field Mode Shapes

Issues:

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Wide area inspection
Complexity

Damage Prognosis

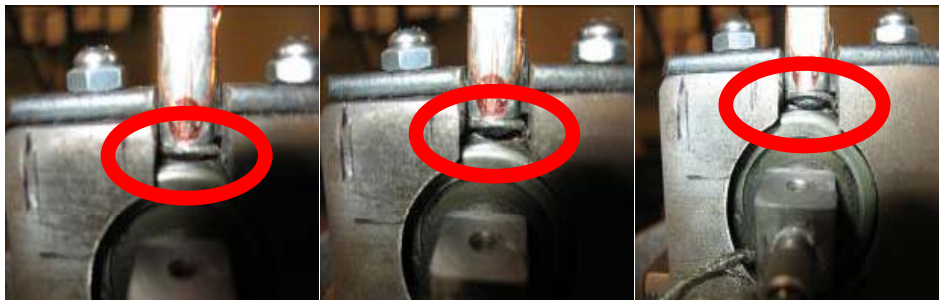
Measurement Complexity in Real-Time Predictive Damage Models

- **Welded steel automotive stabilizer link (subject of recall)**
 - Research on: component damage prediction, effects of usage.

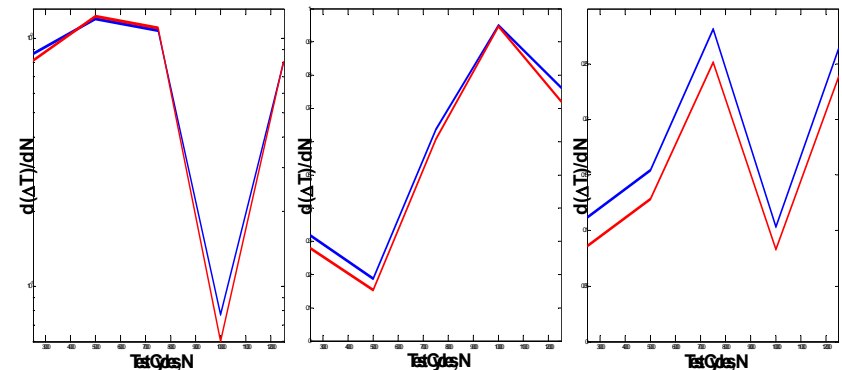


$$\frac{d(DI)}{dN} = C |DI|^m \times |LI|^n$$

Damage growth model



Crack in weld grows under fatigue loading



Model generalizes to other links

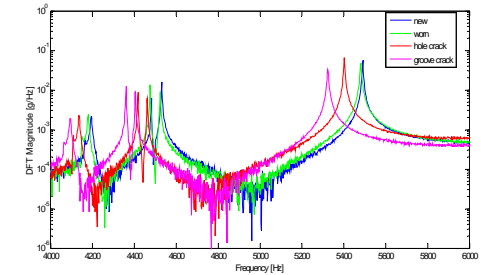
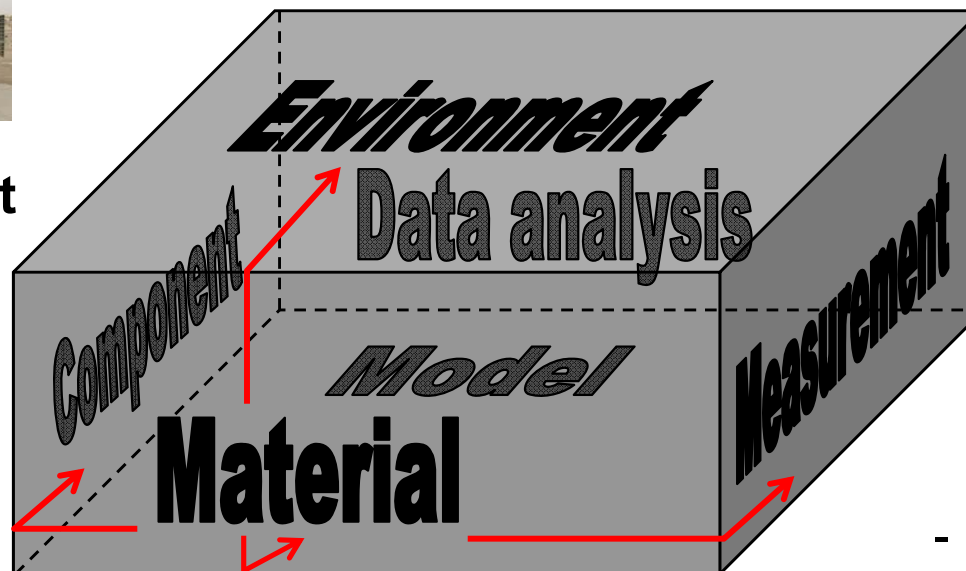
Thinking “in the box”

Basic Needs in Condition Monitoring and Assessment

- Change in properties due to operational variability, maint., etc.
- Methods of data analysis that do not require a reference.



- Variability audit of platforms.
- Modeling interactions.
- Internal load estimation.



- Inexpensive sensor nodes + processing.
- Reliability of sensors and attachments.
- Self-calibration.
- Measurement methodologies.



- Constitutive models (rubber, etc.).
- Dynamic system models.
- Damage/life models.

Need #1: Model-Based Data Interrogation

Data ≠ Information

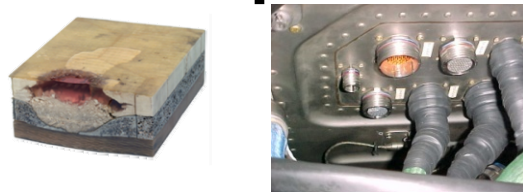
Approach: Models ↔ Simulations ↔ Experiments



Driveline & Track



Suspension



Other (hull, wire harness, etc)

Components
Degradation Mechanisms

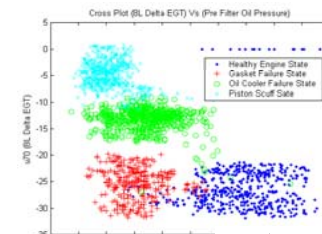


Component Level



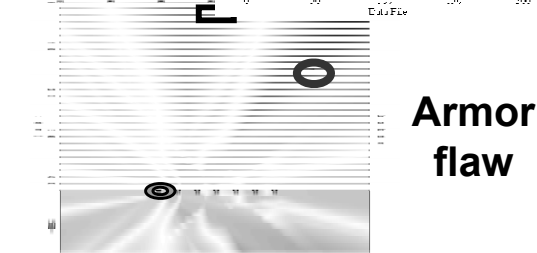
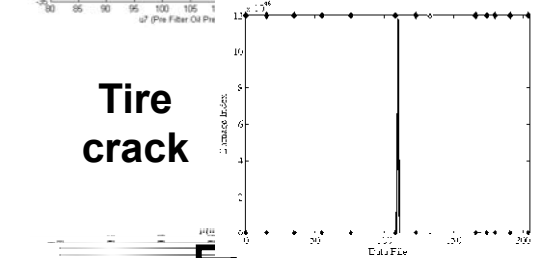
Vehicle Platforms

Systems
Loading Pathways



Engine faults

Tire crack



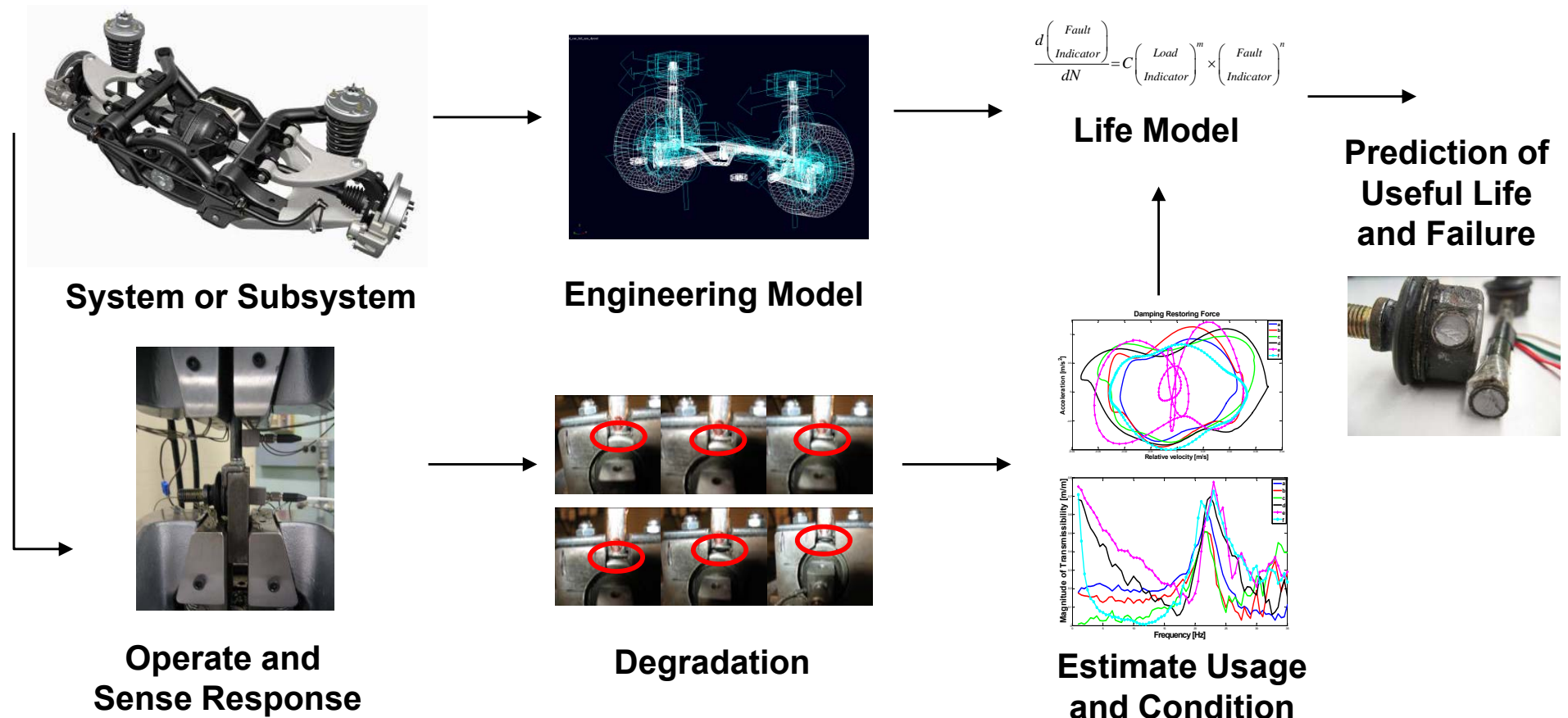
Armor flaw

Data Interrogation
Usage and Fault Estimation

Need #2: Prognostic Modeling

Monitoring ≠ Prediction

Approach: Models ↔ Simulations ↔ Experiments



Acknowledgements

- Graduate RAs at the Herrick Labs
- TARDEC (Mr. Paul Decker, Mr. Joe Gotham, Dr. David Lamb)
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