In-situ Versus Imbedded Sensing - How Health Monitoring Effects Inspection Needs

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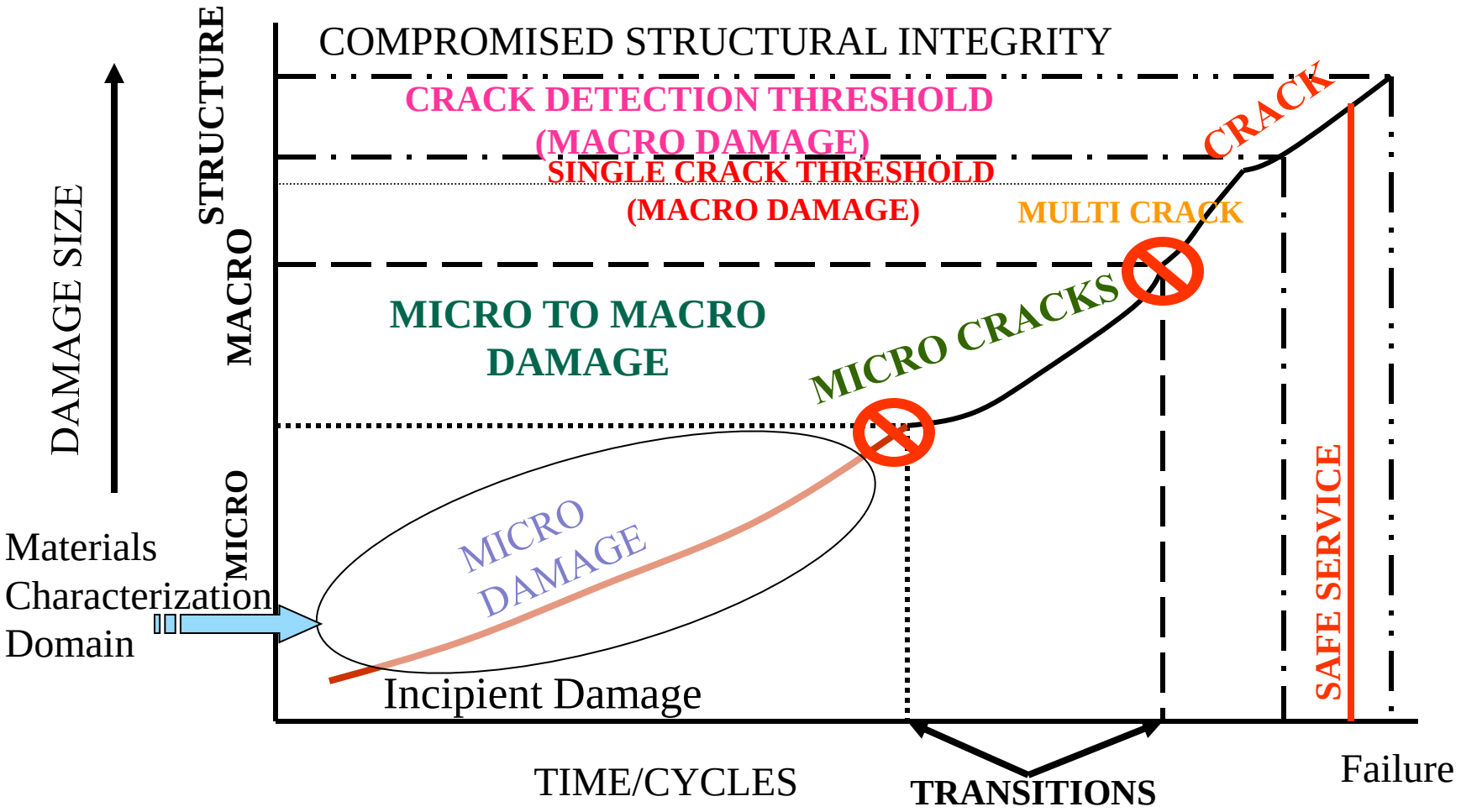
QUANTITATIVE
In-situ Versus Imbedded Sensing - How Structural Health Monitoring Effects Inspection Needs

Structural Materials Diagnostic

MATERIAL DAMAGE DIAGRAM



NDT TECHNOLOGY NEEDS CHANGE AT STAGES OF MATERIALS DAMAGE:
Requires testing tools and model of material damage from micro to macro to structural effects

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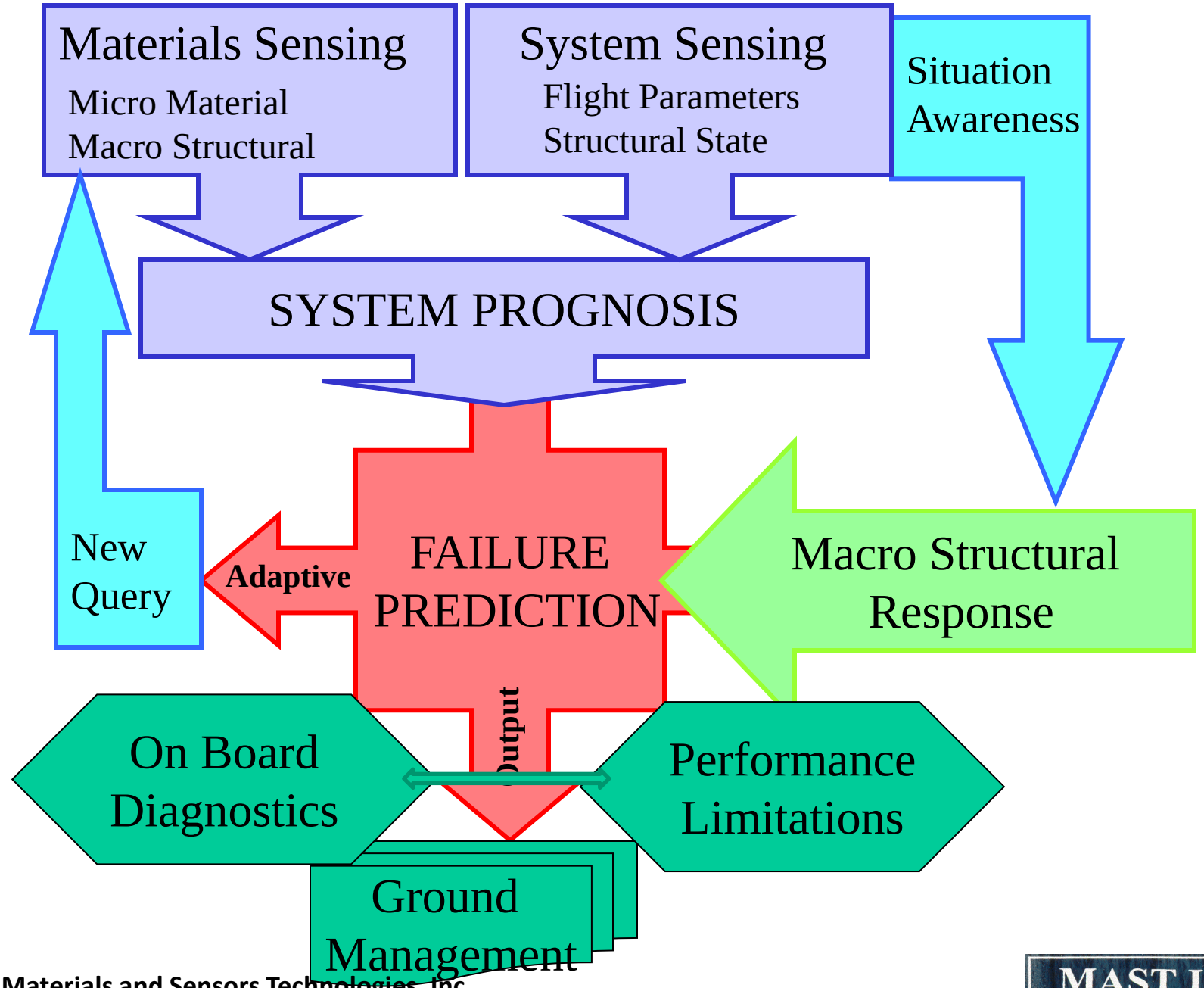
PROGNOSIS METHODOLOGY



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- Prognostic methodology will work if we interactively connect "GLOBAL-LOCAL" picture
- SHM is in need of effective in-situ and embedded sensors
- In-situ sensing technology is more flexible and does not involve structural interaction
- Embedded sensing technology still has ingress/egress limitations and possibly involves structural interactions

Sensing for Prognostic Structural Monitoring -Technology Challenges

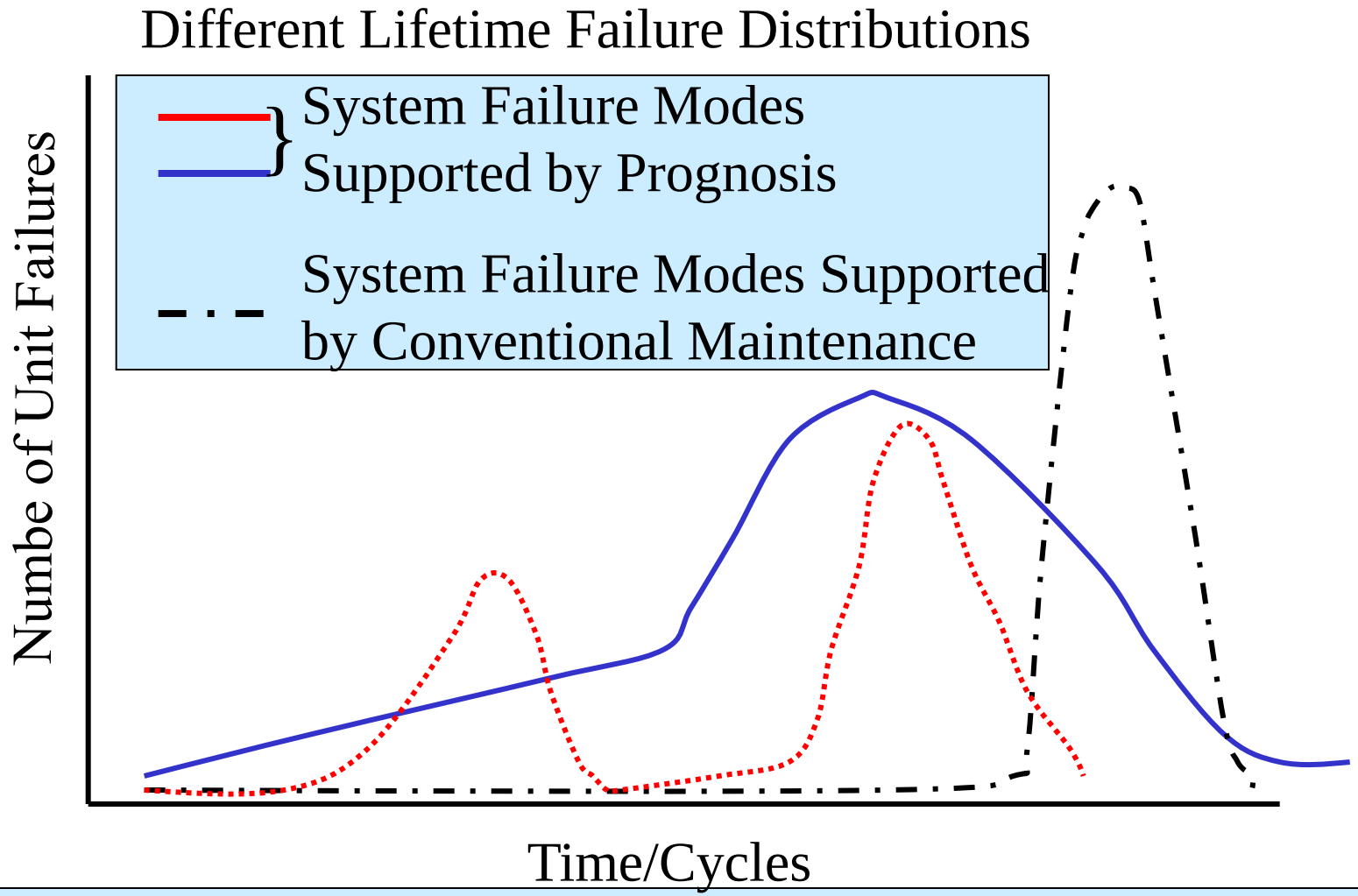
Prognosis Elements	*Technical Challenges*
▪ **Micro-Structural** ***IMATURE TECHNOLOGY***	**Material Characterization Sensing Tools** **Material Degradation Models** **μ-structure-Evolution Models** ***In-Situ* Sensing /Imbedded Sensing** **Uncertainty Quantification Models** **Structure-Property Constitutive Models**
▪ **Macro-Structural** ***MORE MATURE TECHNOLOGY***	**Real-Time Crack Monitoring Sensors** **Sensor Miniaturization & Integration** **Micro to Macro Transition Models** **In-Situ Sensor Integration**

Sensing for Prognostic Structural Monitoring -Technology Challenges

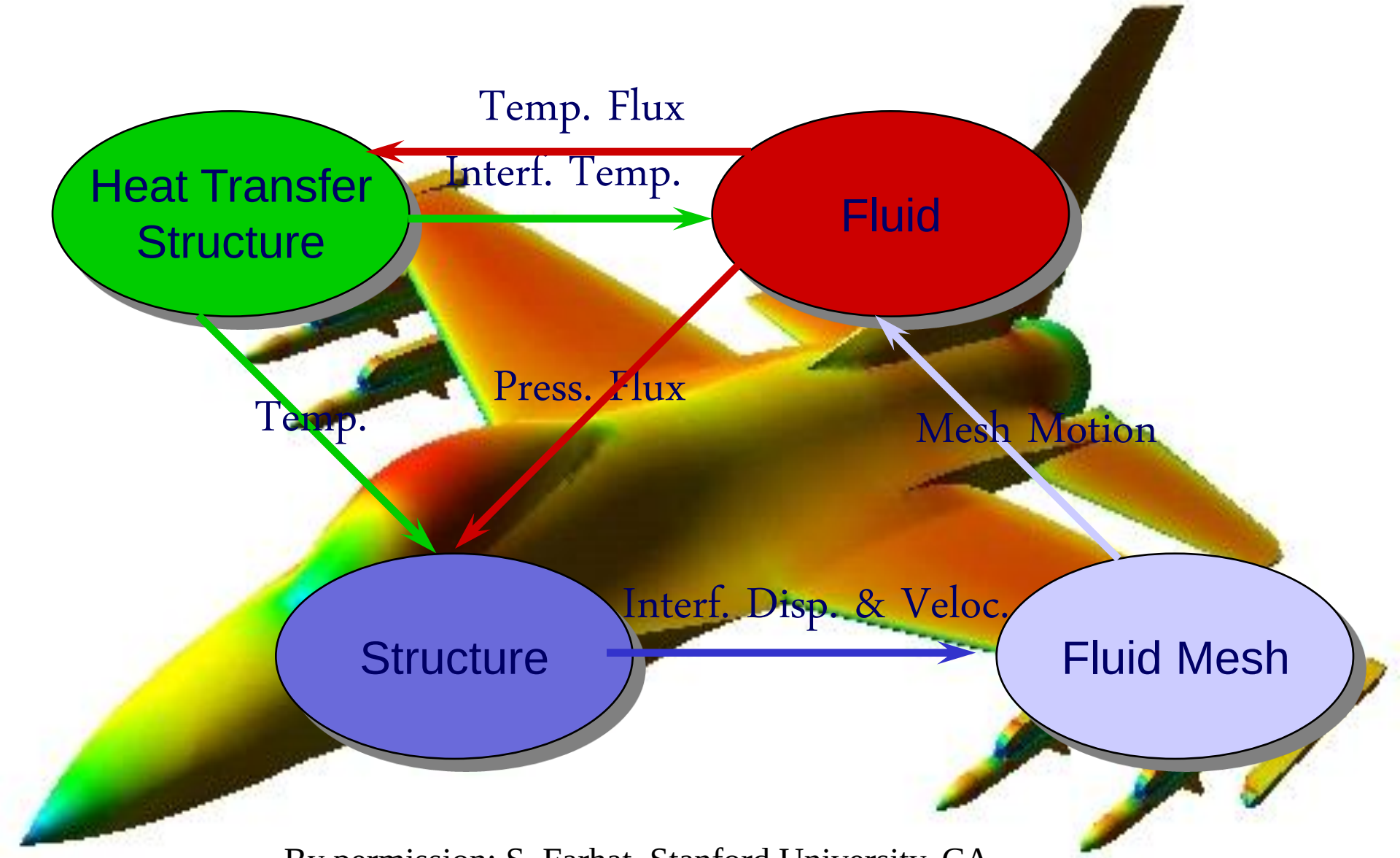
Prognosis Elements	*Technical Challenges*
▪ System-Sensing *MORE MATURE TECHNOLOGY*	Predictive Damage Information Mining Structural Load Sensing Data Fusion Systems Performance Models
▪ System Prognosis *NOT MATURE TECHNOLOGY*	Damage Evolution Prediction Probabilistic Model Dev. & Validation Systems Behavior Models Structural Response Models Adaptive Sensing System Integrity Models Failure Mode Prediction Predictive Life Management

We are Progressing in Micro-Structural Nondestructive Characterization.

- New tools, New models
- Many sensors in development for NDC
- Composite and advanced materials need special attention
- Incipient failure mechanisms need better understanding



PROGNOSTIC HSM PREDICTS SPECIFIC PLATFORM FAILURE POINT ON SYSTEM LIFE PREDICTION DIAGRAM



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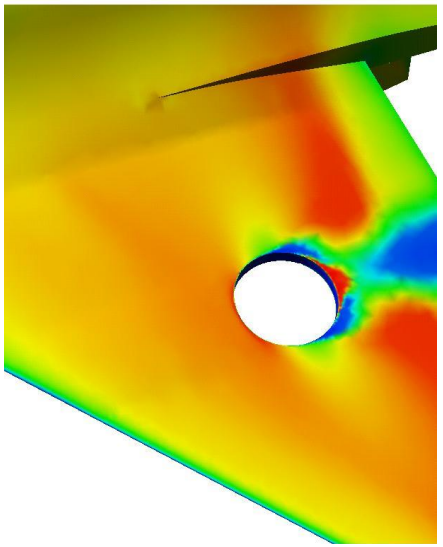
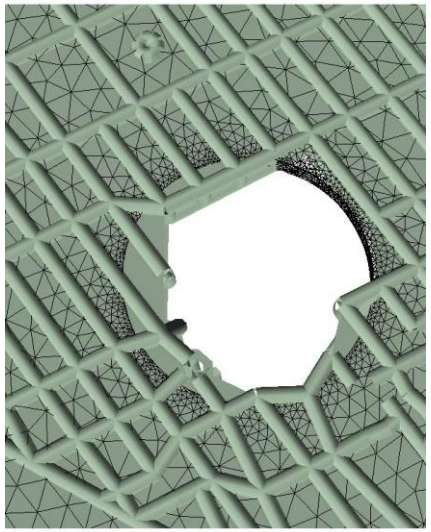
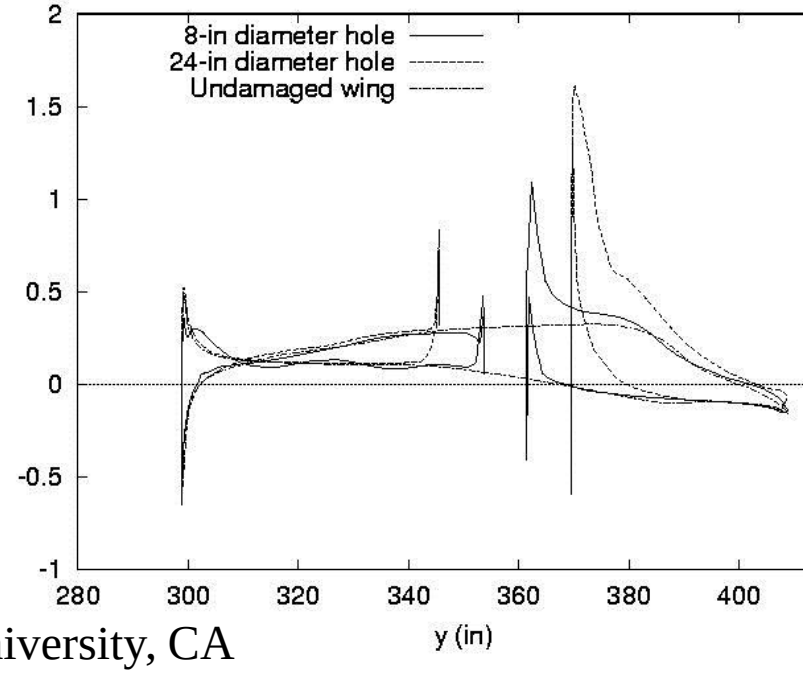
DAMAGE PREDICTION & ASSESSMENT







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Requirements analysis, *What am I testing for?*

- DO WE UNDERSTAND EFFECTS OF DEFECTS?
- WHAT ARE FAILURE MECHANISMS?

• If you use the same old tools without innovative methods, you're going to make the same old discoveries.

•Doing the same thing over and over while expecting different results is definition of insanity.

FOR PLATFORMS:

WHILE DEVELOPING NDI TEST METHOD AND PROCEDURE ONE NEEDS TO ASSESS:

WHAT IS IMPORTANT?
AND
WHAT IS A FAILURE MECHANISM?

Delamination is not necessarily a key defect in the composites

How to select appropriate NDI method/methods?

“ Make objective and quantitative analysis on why would the proposed solution work?”

Key considerations:

- **Defect criteria / Damage Criteria**
- **Defect detection /Damage Detection**
- **Application constraints**

For completeness:

- **Question effects of defects/damage**
- **Consider materials properties**
- **Consider new or emerging technology (Think out of the box)**

How to select appropriate NDI method/methods?

Four important engineering considerations

- Effects of defects or what are inspection targets or criteria (Quantitative).

- What is "considered" appropriate engineering expertise to develop NDE/NDT/NDC process (Engineering).

- NDT method selection process (Justified).

- Development of NDT inspection system (Integrated Engineering).

NOT A RECOMMENDED ATTITUDE

HUMS: Health And Usage Monitoring Systems exist for engines or transmission using existing sensors.
SHM: Structural Health Monitoring systems are not developed.

Open SHM Technology Items:

Do we understand sensing and what we receive?

Do we track signal information from the first principles?

- Ultrasonic,
- Acoustic,
- Guided wave propagation
- Guided Wave sensors

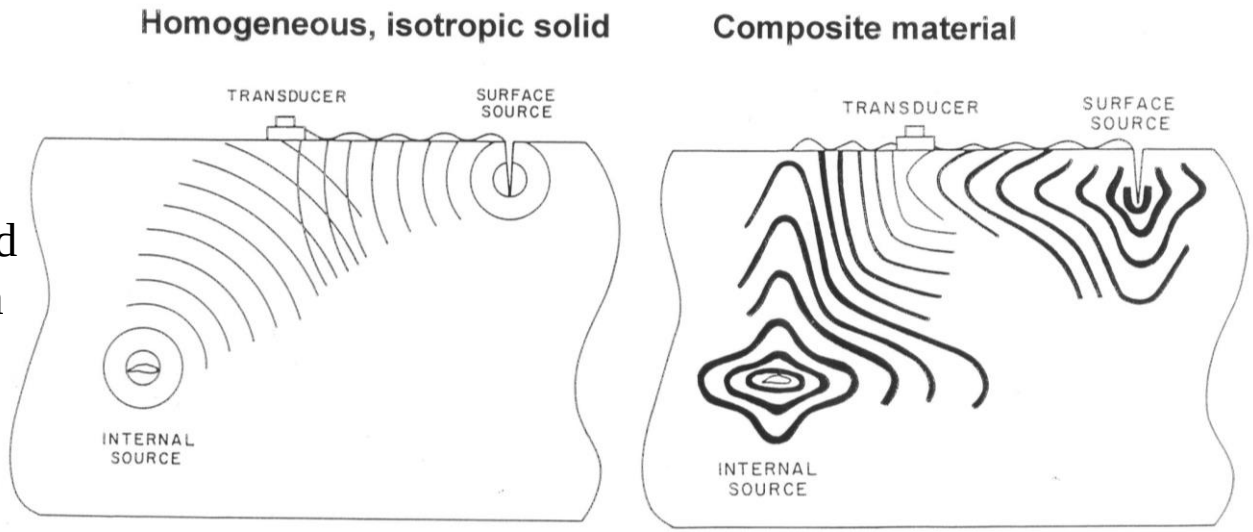
Do we utilize emerging technologies?

- Fiber optic strain sensors for flight in situ sensing/selection
- Acoustical Emission sensors for flight
- Acoustical waveguides for in-situ signal sensing/selection
- Luminescence Sensors
- and others

MANY SHM PROJECTS USE THE GUIDED WAVE ULTRASONIC

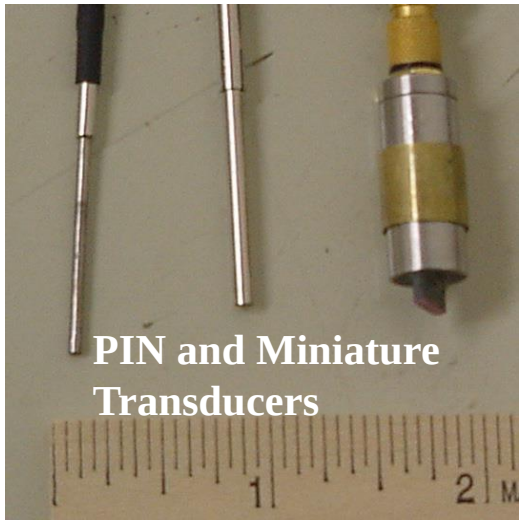
- **Guided wave tests on difficult geometry require appropriate selection of transducers and signal processing.**
- **Guided waves reach zones not testable using conventional ultrasonic approaches.**
- **Composite materials add complexity to the test parameters.**

Acoustic Emission is strongly influenced by wave propagation

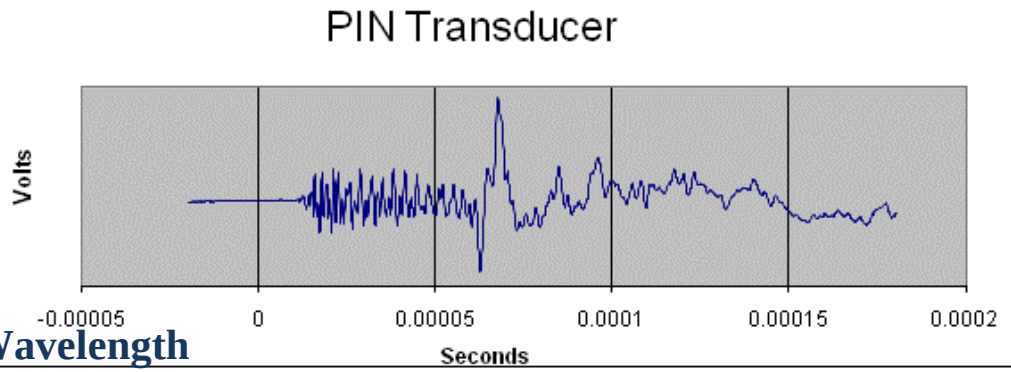


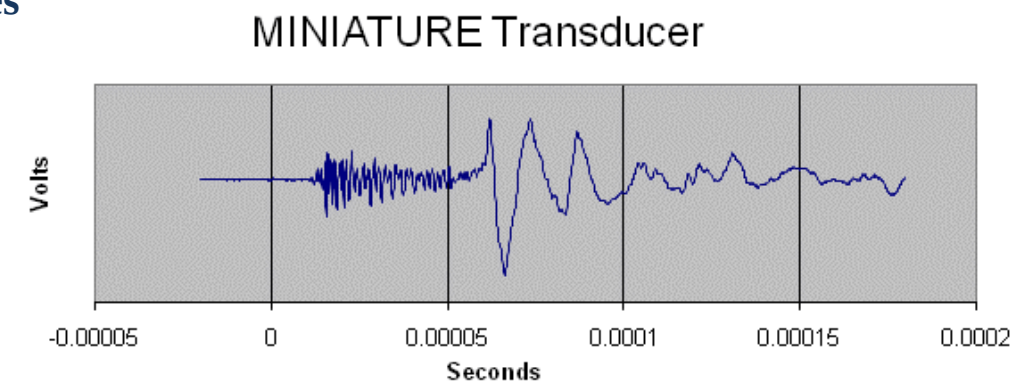
ASSUMPTION **REALITY**

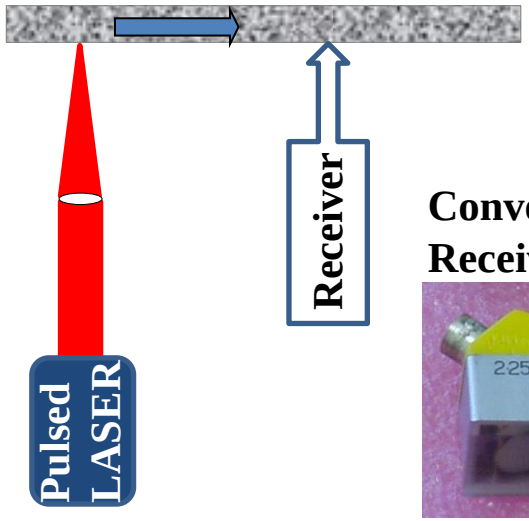
Sensing Transducer Performance, small vs large aperture vs wedge



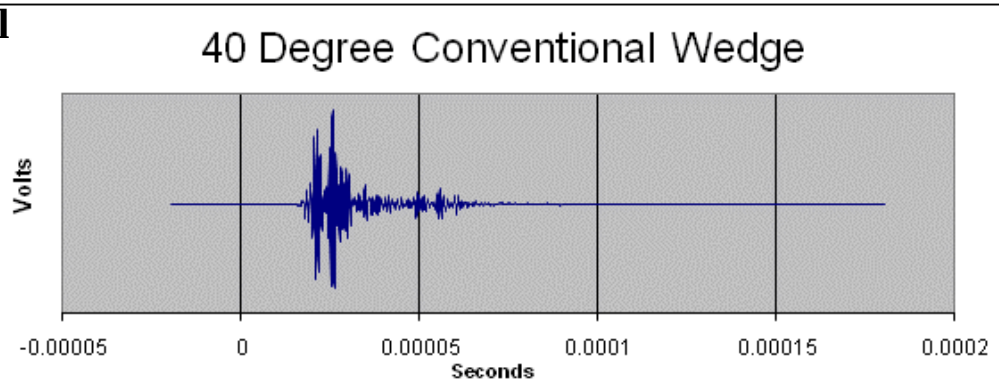
Sub-Wavelength Probes







Conventional Receiver



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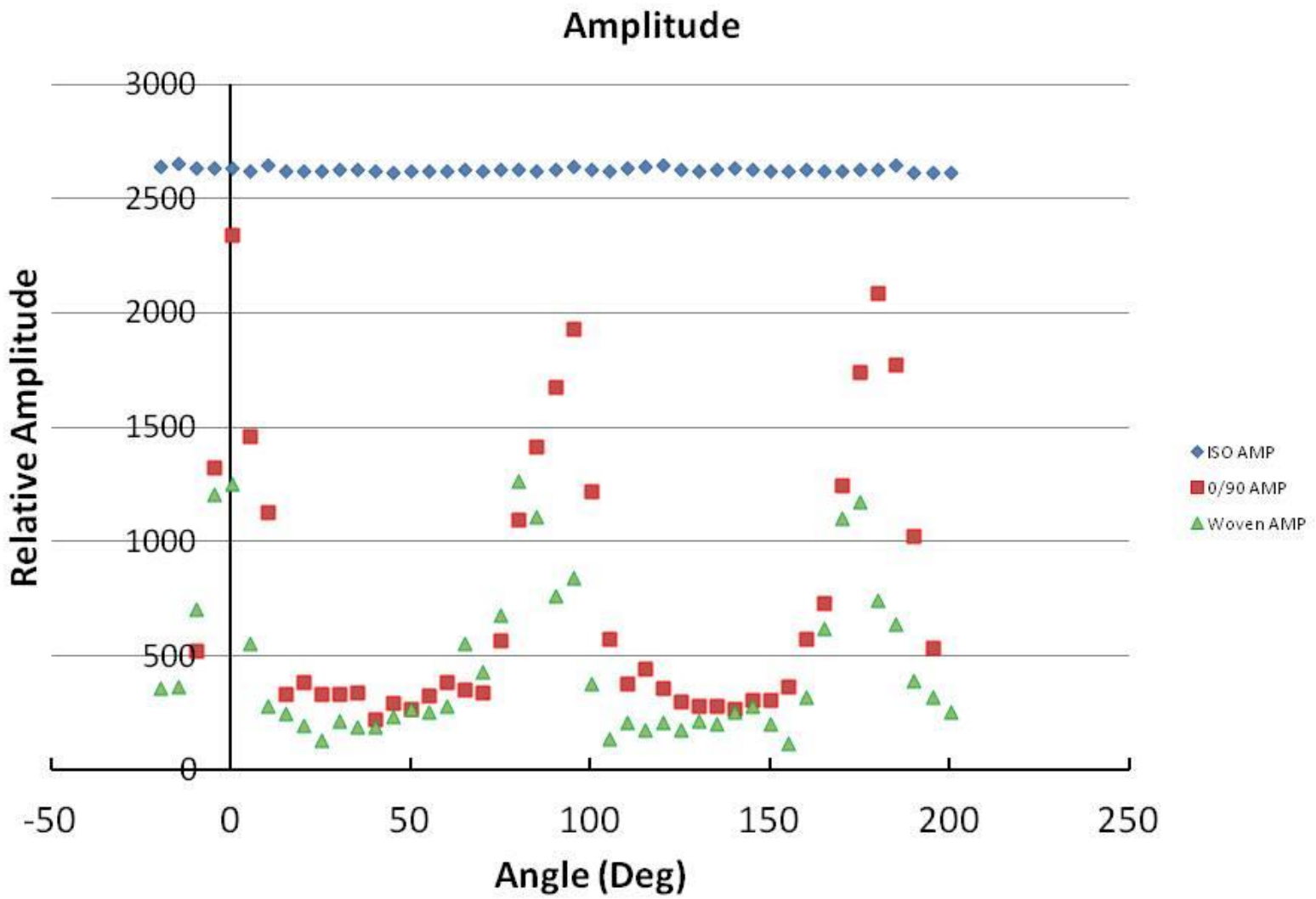
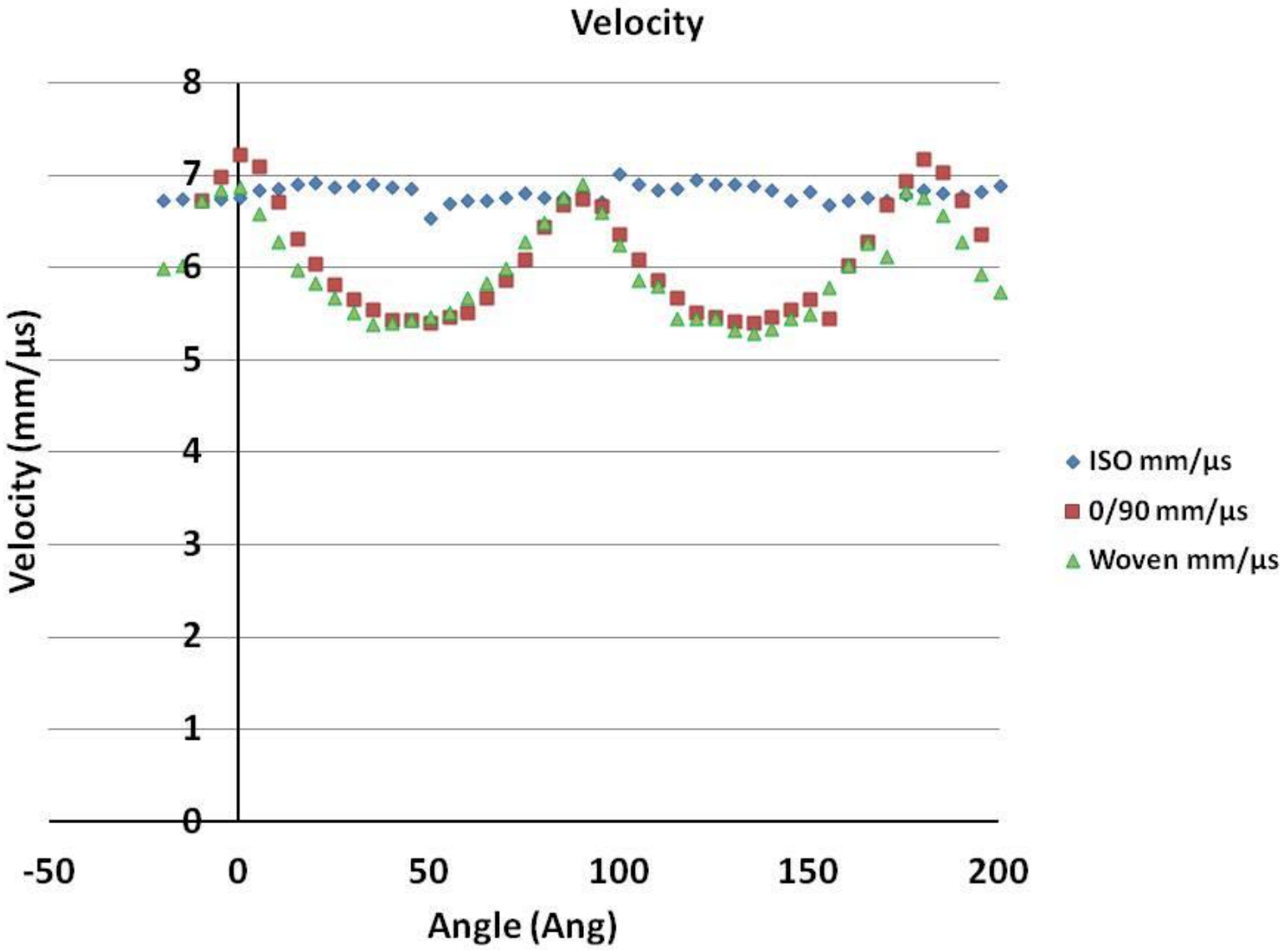
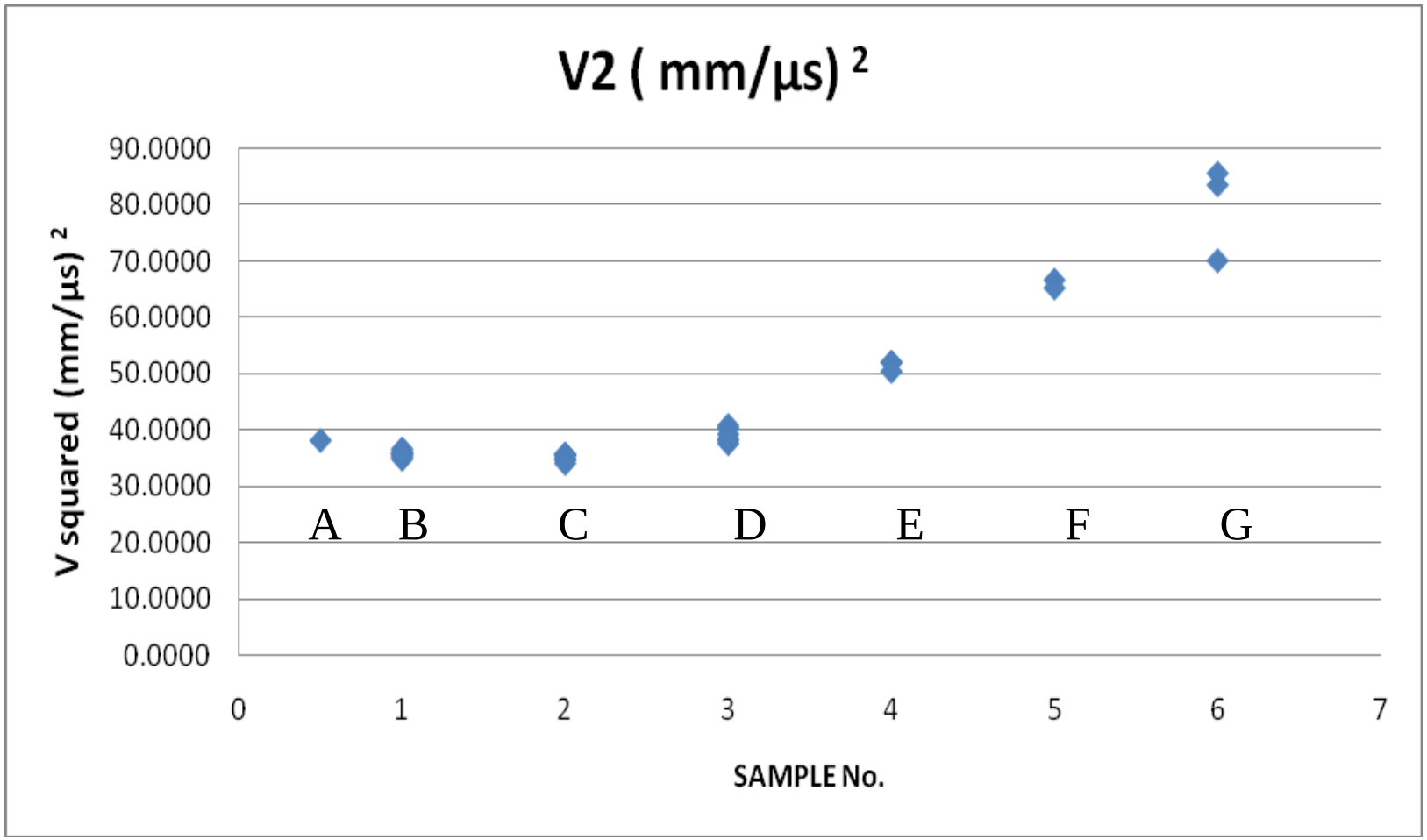




Direct Sensing of the Composite Materials Elastic Modulus

Plot of composite samples velocity with different modulus



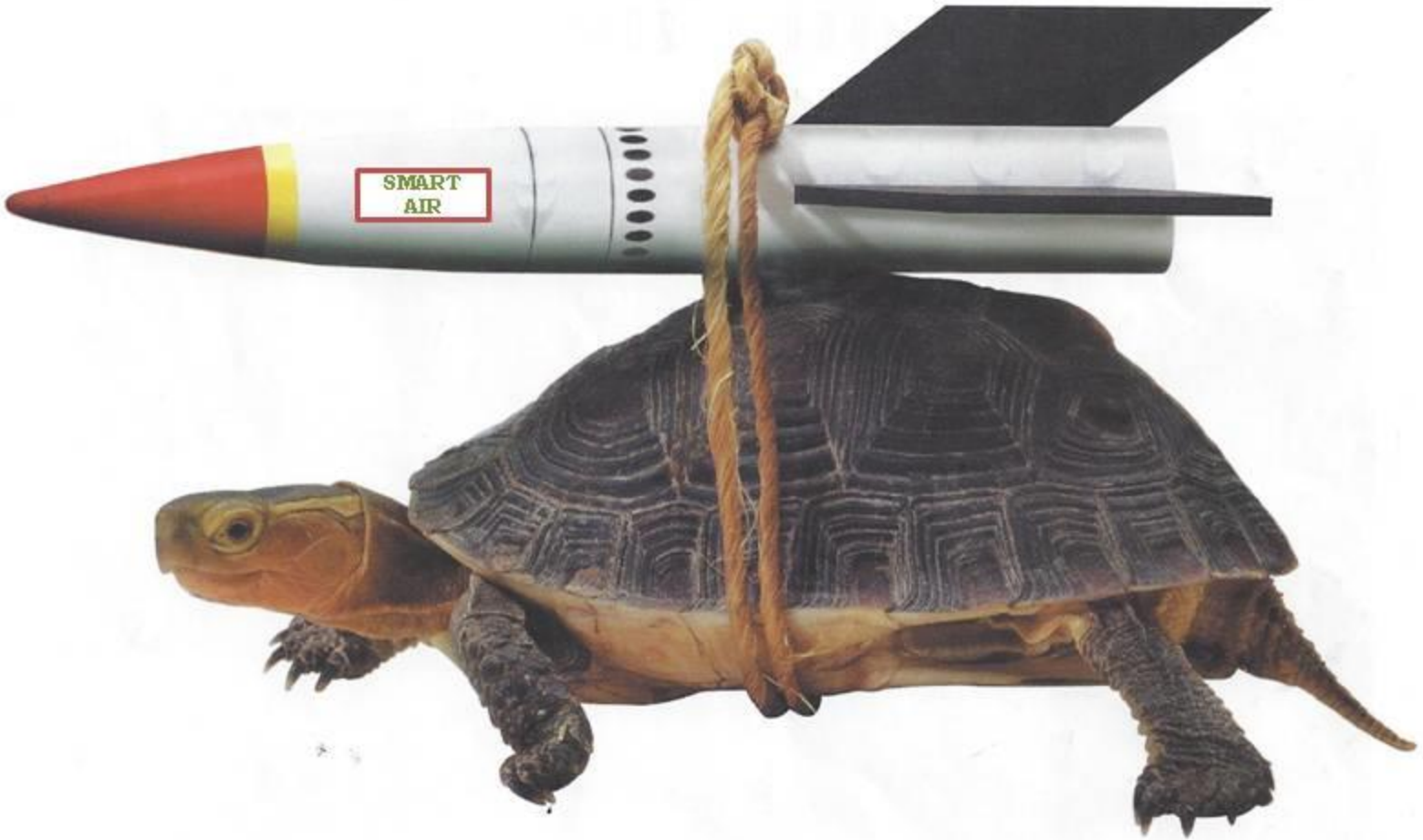
POINTS OF DISCUSSION

SOME QUESTIONS:

Is technical community willing to do the investment?
Is technical community ready for interdisciplinary work?
Will system designer accept the concept?
What is time table to get there?
Who will carry technology development burden?
Can we stay on track without too many back steps?
What technologies do we pursue?
How is in-situ NDE integrated into operations?
How is prognostic NDE integrated into operations?

THE IMPACT OF PROGNOSTIC NDE WILL BE ENORMOUS

The best solutions combine **wisdom** and **speed**.



PROGNOSTIC HEALTH STRUCTURAL MONITORING

THE IMPACT OF PROGNOSTIC NDI IS ENORMOUS

- ❑ System reliability
- ❑ Time saving
- ❑ Logistic improvements
- ❑ Cost saving…

In-situ NDE enables real time "Prognostic" structural assessments methodology that enables safer and more efficient management of structures.

In a long duration space mission, it is survival.